

BS 5930:2015



BSI Standards Publication

# Code of practice for ground investigations

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Published by BSI Standards Limited 2015

ISBN 978 0 580 80062 7

ICS 91.200

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

Committee reference B/526/3

Draft for comment 14/30268442 DC

**Publication history**

First published 1957

Second edition 1981

Third edition October 1999

Fourth (present) edition July 2015

**Amendments issued since publication**

| <b>Date</b> | <b>Text affected</b> |
|-------------|----------------------|
|-------------|----------------------|

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### Summary of pages

This document comprises a front cover, an inside front cover, pages i to vi, pages 1 to 318, an inside back cover and a back cover.

## Foreword

### Publishing information

This British Standard is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 31 July 2015. It was prepared by Subcommittee B/526/3, *Site investigation and ground testing*, under the authority of Technical Committee B/526, *Geotechnics*. A list of organizations represented on this committee can be obtained on request to its secretary.

### Supersession

This British Standard supersedes BS 5930:1999+A2:2010, which is withdrawn.

### Information about this document

The first edition of this British Standard (published as CP2001:1957) covered basic guidance on effective ground investigation. This was replaced by full editions in 1981 and 1999, which covered the subject matter in greater detail and each of which was brought up to date at the time of publication. The 1999 edition was amended twice to incorporate changes necessary to maintain compliance with BS EN 1997-1 and BS EN 1997-2 and their related standards.

This is a full revision of the standard, and introduces the following principal changes:

- The majority of changes arise from the further implementation into UK practice of BS EN 1997-1 and BS EN 1997-2 and the related test standards cited therein and the need to conform to these standards.
- The revision of material that is now out of date. There is new information on geophysical surveying and ground testing and updated guidance on ground investigations on contaminated ground, changes to accommodate the requirements of data capture in the field and the inclusion of this in reporting as well as other amendments throughout the code.

**Product certification.** Users of this British Standard are advised to consider the desirability of third-party certification with this British Standard. Appropriate conformity attestation arrangements are described in BS 22475-3. Users seeking assistance in identifying appropriate conformity assessment bodies or schemes may ask BSI to forward their enquiries to the relevant association.

**Test laboratory accreditation.** Users of this British Standard are advised to consider the desirability of selecting test laboratories that are accredited to BS EN ISO/IEC 17025 by a national or international accreditation body.

### Use of this document

As a code of practice, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

Any user claiming compliance with this British Standard is expected to be able to justify any course of action that deviates from its recommendations.

It has been assumed in the preparation of this British Standard that the execution of its provisions will be entrusted to appropriately qualified and experienced people, for whose use it has been produced.

### **Presentational conventions**

The provisions of this standard are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is “should”.

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

The word “should” is used to express recommendations of this standard. The word “may” is used in the text to express permissibility, e.g. as an alternative to the primary recommendation of the clause. The word “can” is used to express possibility, e.g. a consequence of an action or an event.

Notes and commentaries are provided throughout the text of this standard. Notes give references and additional information that are important but do not form part of the recommendations. Commentaries give background information.

### **Contractual and legal considerations**

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

**Compliance with a British Standard cannot confer immunity from legal obligations.**



## Introduction

The ground is naturally variable and often the nature of these variations is not known. A ground investigation is a process starting with initial documentation about the site and its environs followed by continuous exploration and interpretation, with the scope of the investigation requiring regular amendment in the light of the data being obtained.

This British Standard is set out to follow, in broad terms, the sequence of a ground investigation from initial considerations through the phased design and implementation of an investigation programme and its reporting, to the continuing investigation during and after construction.

Section 1 of this British Standard deals with those matters of a technical, legal or environmental character that need 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. The safety of all those involved in investigation, including the general public and the environment, is also introduced here to emphasize its fundamental importance in the execution of all aspects of the investigation; this coverage is referred to but not repeated throughout the standard.

Section 2 outlines the procedures that should be followed and the information that should be collected in desk studies and field reconnaissance.

Section 3 discusses general aspects of planning investigations, including the factors that influence the selection of methods of investigation.

Section 4 discusses methods of intrusive investigation, including overwater investigations (i.e. those carried out using land-based methods), sub-divided into excavations and boreholes, sampling, and groundwater observations.

Section 5 outlines the methods of geophysics that can be used for ground mapping, characterization and testing, from the ground surface, boreholes, crosshole and surface to borehole and overwater.

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

Section 7 describes the range of field tests that can be considered to measure appropriate geotechnical parameters.

Section 8 outlines the instrumentation that can be used to measure parameters or monitor field conditions.

Section 9 describes the range of laboratory tests on samples that can be used to measure a range of geotechnical parameters for material classification and use in design.

Section 10 provides details of the information that is to be included in field reports, the presentation and evaluation of factual information in the investigation report and in the interpretation of the data obtained from the investigation and the preparation of the design report.

Section 11 describes the requirements of investigation that continues into and beyond the construction phase, including the requirements for monitoring and maintenance of the structure.

Users of this British Standard, particularly those with limited experience, are advised to study the preliminary considerations in Section 1 and Section 2 before referring to the methods of ground investigation in Section 3 to Section 10. Development continues to take place, and this is likely to involve changes in some of the methods. For this reason it is important to ensure that the planning, supervision and interpretation of results of any investigation is carried out by suitably qualified and experienced specialists (see Clause 6).

It might 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 in national and international standards whereas there is a paucity of reference to other tests.

This British Standard has been drawn up mainly in relation to conditions existing in the United Kingdom, but reference is made to technical and professional practice in other countries where relevant.

In this British Standard the term ground investigation (previously called site investigation in the UK) is used in the wider sense of investigation of the site, which includes desk studies, field reconnaissance and field and laboratory work within the broad geographical, geological, hydrogeological and environmental contexts.

## 1 Scope

This British Standard gives recommendations for 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 could affect the design and construction of such work and the security of neighbouring land and property.

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

This British Standard provides guidance on the application of BS EN 1997-1 and BS EN 1997-2 and the related test standards cited therein.

It does not provide guidance on investigations for contamination or naturally elevated concentrations of potentially hazardous substances (these are dealt with in BS 10175). Nor does it provide guidance on investigations for ground gas (these are dealt with in BS 8576). However, it does provide guidance on the integration of geotechnical investigations with investigations for contamination or ground gas and other types of investigations (e.g. archaeological).

## 2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

### Standards publications

BS 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 1377-6:1990, *Methods of test for soils for civil engineering purposes – Part 6: Consolidation and permeability tests in hydraulic cells and with pore pressure measurement*

- 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 8550, *Guide for the auditing of water quality sampling*
- BS 8574, *Code of practice for the management of geotechnical data for ground engineering projects*
- BS 8576:2013, *Guidance on investigations for ground gas – Permanent gases and Volatile Organic Compounds (VOCs)*
- BS 10175:2011+A1:2013, *Investigation of potentially contaminated sites – Code of practice*
- BS 22475-3:2011, *Geotechnical investigation and testing – Sampling methods and groundwater measurements – Part 3: Conformity assessment of enterprises and personnel by third party*
- BS EN 1997-1:2004+A1:2013, *Eurocode 7: Geotechnical design – Part 1: General rules*
- BS EN 1997-2:2007, *Eurocode 7: Geotechnical design – Part 2: Ground investigation and testing*
- BS EN ISO 5667-1, *Water quality – Sampling – Guidance on the design of sampling programmes and sampling techniques*
- BS EN ISO 5667-3, *Water quality – Sampling – Preservation and handling of water samples*
- BS EN ISO 10545-8, *Ceramic tiles – Determination of linear thermal expansion*
- 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 17892-1, *Geotechnical investigation and testing – Laboratory testing of soil – Determination of water content*
- BS EN ISO 17892-2, *Geotechnical investigation and testing – Laboratory testing of soil – Determination of bulk density*
- BS EN ISO 18674, *Geotechnical investigation and testing – Geotechnical monitoring by field instrumentation – General rules*
- BS EN ISO 22282-1, *Geotechnical investigation and testing – Geohydraulic testing – Part 1: General rules*
- BS EN ISO 22282-2, *Geotechnical investigation and testing – Geohydraulic testing – Part 2: Water permeability tests in a borehole using open systems*
- BS EN ISO 22282-3, *Geotechnical investigation and testing – Geohydraulic testing – Part 3: Water pressure tests in rock*
- BS EN ISO 22282-4, *Geotechnical investigation and testing – Geohydraulic testing – Part 4: Pumping tests*
- BS EN ISO 22282-5, *Geotechnical investigation and testing – Geohydraulic testing – Part 5: Infiltration tests*

BS EN ISO 22282-6, *Geotechnical investigation and testing – Geohydraulic testing – Part 6: Water permeability tests in a borehole using closed systems*

BS EN ISO 22475-1:2006, *Geotechnical investigation and testing – Sampling methods and groundwater measurements – Part 1: Technical principles for execution*

BS EN ISO 22476-1, *Geotechnical investigation and testing – Field testing – Part 1: Electrical cone and piezocone penetration test*

BS EN ISO 22476-2, *Geotechnical investigation and testing – Field testing – Part 2: Dynamic probing*

BS EN ISO 22476-3, *Geotechnical investigation and testing – Field testing – Part 3: Standard penetration test*

BS EN ISO 22476-4, *Geotechnical investigation and testing – Field testing – Part 4: Ménard pressuremeter test*

BS EN ISO 22476-5, *Geotechnical investigation and testing – Field testing – Part 5: Flexible dilatometer test*

BS EN ISO 22476-6, *Geotechnical investigation and testing – Field testing – Part 6: Self boring pressuremeter test*<sup>1)</sup>

BS EN ISO 22476-7, *Geotechnical investigation and testing – Field testing – Part 7: Borehole jack test*

BS EN ISO 22476-8, *Geotechnical investigation and testing – Field testing – Part 8: Full displacement pressuremeter test*<sup>2)</sup>

BS EN ISO 22476-9, *Geotechnical investigation and testing – Field testing – Part 9: Field vane test*<sup>3)</sup>

BS EN ISO 22476-12, *Geotechnical investigation and testing – Field testing – Part 12: Mechanical cone penetration test (CPTM)*

BS ISO 5667-11, *Water quality – Sampling – Guidance on sampling of groundwaters*

BS ISO 5667-22, *Water quality – Sampling – Guidance on the design and installation of groundwater monitoring points*

ISO/TS 22476-11, *Geotechnical investigation and testing – Field testing – Part 11: Flat dilatometer test*

NA to BS EN 1997-2:2007, *UK National Annex to Eurocode 7: Geotechnical design – Part 2: Ground investigation and testing*

PAS 128, *Specification for underground utility detection, verification and location*

#### **Other publications**

[N1] BUILDING RESEARCH ESTABLISHMENT. *Concrete in aggressive ground, BRE Special Digest 1*. Watford: BRE, 2005.

[N2] INTERNATIONAL SOCIETY FOR ROCK MECHANICS. Commission on standardisation of laboratory and field tests. Suggested methods for rock stress determination. *In: Int. Jour. Rock Mechanics and Mining Sciences and Geomech. Abstract*. 1987, 24(1), 53-73.

[N3] BUILDING RESEARCH ESTABLISHMENT. *Soakaway design. BRE Digest 365*. Watford: BRE, 1991.

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<sup>1)</sup> In preparation.

<sup>2)</sup> In preparation.

<sup>3)</sup> In preparation.

## 3 Terms and definitions

For the purposes of this British Standard, the terms and definitions given in BS EN 1997-1, BS EN 1997-2 and the following apply.

### 3.1 anthropogenic ground

deposits which have accumulated through human activity

*NOTE* These could consist of natural materials placed/replaced by man, e.g. clay, or man-made materials, e.g. refuse.

### 3.2 contamination

presence of a substance or agent, as a result of human activity, in, on or under land, which has the potential to cause harm or to cause pollution

[SOURCE: BS 10175:2011+A1:2013, 3.1.3]

*NOTE 1* There is no assumption in this definition that harm results from the presence of the contamination.

*NOTE 2* Potentially hazardous substances of natural origin (e.g. radon, arsenic, lead) might also be present in the ground.

### 3.3 exploratory hole

investigation point comprising an excavation or borehole from which visual descriptions can be made and samples can be taken or in which tests can be made

### 3.4 fill

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

### 3.5 ground

all materials below the ground surface, including natural materials (soil and rock) and anthropogenic materials

### 3.6 ground investigation

investigation of the site in a broad sense which includes desk studies, field reconnaissance, and field and laboratory work within geographical, geological, hydrogeological and environmental contexts

*NOTE* Previously called site investigation in the UK.

### 3.7 ground model

outline of the understanding of the disposition and character of soil, rock and groundwater under and around the site

### 3.8 groundwater

water located beneath the surface of the earth

### 3.9 groundwater control

measures taken to control the groundwater conditions to mitigate effects on investigation or engineering works

*NOTE* This term has been adopted in preference to the less specific term "dewatering".

### 3.10 made ground

anthropogenic ground in which the material has been placed without engineering control and/or manufactured by man in some way, such as through crushing or washing, or arising from an industrial process

**3.11 permanent gas**

element or compound that is a gas at all ambient temperatures likely to be encountered on the surface of the earth

*NOTE Under extreme hot circumstances, some substances might become gases that would not otherwise be. These are not permanent gases.*

[SOURCE: BS 8576:2013, 3.10]

**3.12 rock**

naturally occurring assemblage of minerals, crystallized, consolidated, cemented, or otherwise bonded together, so as to form material of generally greater strength or stiffness than soils

[SOURCE: Adapted from BS EN ISO 14689-1:2003, 3.1]

**3.13 soil**

assemblage of mineral particles and/or organic matter which can be separated by gentle mechanical means and which includes variable amounts of water and air (and sometimes other gases)

*NOTE 1 The term is also applied to anthropogenic ground consisting of replaced natural soil or man-made materials exhibiting similar behaviour, e.g. crushed rock, blast furnace slag, fly-ash.*

*NOTE 2 Soils might have structures and textures derived from rock but are usually of lower strength than rocks.*

**3.14 Volatile Organic Compound (VOC)**

organic compound that is volatile under normal environmental/atmospheric conditions, although it can be found in the ground in the solid, liquid and dissolved phase form as well as in gaseous phase

[SOURCE: BS 8576:2013, 3.15]

*NOTE 1 VOC can also be defined as an "organic compound which is liquid at 20 °C and which generally has a boiling point below 180 °C" (based on BS EN ISO 11074:2015).*

*NOTE 2 Examples include single-ring aromatic hydrocarbons and other low boiling halogenated hydrocarbons, which are used as solvents or fuels, and some degradation products.*

# Section 1: Preliminary considerations

## 4 Primary objectives

### COMMENTARY ON CLAUSE 4

*The amount and types of investigation can vary from the very simple, e.g. a visual inspection, to simple probing or boring to establish the level of an easily recognized rock-head, to the highly complex, involving sophisticated techniques for boring, sampling and testing; the selection of which methods to adopt are controlled by the primary objectives identified.*

*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 might need detailed investigation before the final choice is made.*

The identification of the objectives of the investigation should follow the requirements specified in BS EN 1997-2.

The primary objectives when carrying out ground investigations should include the following, as appropriate.

- a) Choice of site – where alternatives exist, to advise on the relative suitability of different sites, or different parts of the same site.
- b) 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.
- c) Design – to enable an adequate and economic design to be prepared, including the design of temporary works.
- d) Existing works – unless the contrary can be demonstrated, it should be assumed that ground investigations are necessary when reporting upon the existing works (see 15.2), and for investigating cases where failure has occurred (see 15.3). The objectives of such investigations should be directly related to the particular problems involved.
- e) Effect of changes – to determine the changes that might arise in the ground and surrounding environment, either naturally or as a result of the works, and the effect of such changes on the works and on adjacent works.
- f) Construction – to plan the best method of construction; to foresee and provide against difficulties and delays that could arise during construction due to ground, groundwater and other local conditions; in appropriate cases, to explore sources of indigenous materials for use in construction; and to select sites for the disposal of waste or surplus materials. (See 15.4 for recommendations for investigation of materials for construction purposes.)

A ground model for the site should be constructed at the very beginning of the investigation process; this model is used to identify the known conditions and, importantly, uncertainties in the knowledge of the ground, and so identify the investigations required. The model should be continuously updated in the light of the investigation findings. A register identifying the risks posed by the ground should be prepared and maintained in parallel with the ground model.

*NOTE The register of risks to the investigation and the engineering works referred to here is separate from, and additional to, the site safety plan which identifies the health and safety risks associated with the ground investigation that might affect workers on the site, the public and the environment (see Clause 5 and Section 2).*

Ground investigations should obtain reliable information to enable an economic and safe design, to assess any hazards (physical or chemical) associated with the ground, and to meet design and construction requirements. At each stage, the investigation should be designed to verify and expand the information previously collected.

An objective of the ground investigation should be to obtain a clear understanding of the geomorphology, geology and hydrogeology of the site through appropriate desk study, site reconnaissance, mapping and intrusive field investigations.

The geological profile should be established by visual inspection and systematic description of the ground using the methods and terminology given in Section 3 to Section 8. The understanding of the profile should be supplemented by field and laboratory testing to determine the engineering properties of the geological materials encountered in detail (see Clause 15 for the scope of field investigations).

In order to evaluate fully the nature of the ground and the groundwater and so as to achieve the objectives of the ground investigation, the work should be planned, undertaken and supervised by personnel who have suitable qualifications, skills and experience relevant to the particular aspects of geotechnical work on the site (see Clause 6).

The investigation should cover all ground in which significant temporary or permanent changes might occur as a result of the works (these include changes in stress and associated strain; changes in water 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 might deteriorate, especially in landfill and contaminated former industrial sites; therefore, information should be provided from which an estimate of the corrosivity and aggressiveness of the ground can be made (see Clause 21 and Clause 61).

Wherever appropriate, measures should be taken to locate natural and man-made underground cavities, such as old mine entries, mine workings or swallow holes, which could collapse and cause damage. Other hazards could also arise on account of earlier uses of the site (see Clause 12).

## 5 Safety on investigation sites

### COMMENTARY ON CLAUSE 5

*A summary of relevant health and safety regulations is given in Annex A.*

*After this introductory clause, 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 all persons involved in any and every activity in ground investigation and this includes the protection of the general public and the environment.*

### 5.1 General

This British Standard describes procedures for ground investigations which inevitably involve some risk to site personnel, the public and the environment. Risk assessments should be carried out and an appropriate construction phase plan should be prepared beforehand and implemented at all stages of the work.

A construction phase plan should be prepared before any physical work is carried out, including field reconnaissance; robust safety starts with the identification of risks and appropriate mitigation measures. This plan should be maintained throughout the investigation and reviewed as and when any unexpected conditions are encountered.



The following procedures should be carried out:

- a) any potential hazards that might exist when carrying out ground investigations should be identified;
- b) a framework for safe working should be established following the principles of hazard removal, replacement or reduction in that order (this framework should be communicated to all workers before the start of works, and refreshed as appropriate through regular toolbox talks);
- c) working procedures to minimize risks from contaminants and physical hazards associated with the collection, transport, testing and disposal of samples and the use of machinery should be adopted;
- d) personal protection equipment and cleaning facilities to minimize any risks should be available; and
- e) procedures for response in the case of an accident should be available.

Safety documentation and procedures should take into account that even risks which people are familiar with on an everyday basis can increase in a working environment that is unfamiliar.

Where the use of hand tools could cause vibration-induced occupational health issues, e.g. in sampling or installation of instrumentation, appropriate control of risks should be implemented.

These steps cannot remove all risk from the site works and, therefore, the need for all personnel to exercise all due care and caution at all times should be emphasized.

*NOTE* This British Standard does not seek to address everyday hazards that might arise from the use of such items as sharp instruments, digging equipment, or the hazards of driving to and from a site. It is assumed that such hazards are satisfactorily dealt with by the personnel carrying out the investigation.

Investigation sites should be kept secure at all times so that members of the public cannot be injured; this includes ensuring that areas of the works such as excavations, boreholes and spoil materials are fenced off until restoration is complete. Instrument head works or reading cabinets should be secure, fenced off and highlighted.

## 5.2 Contaminated land and gas

Guidance on site safety issues to be addressed in any investigation involving contaminated land or gas affected sites should be obtained from BS 10175 (in particular Annex C of that standard), BS ISO 10381-3 and industry guidance.

*NOTE 1* The following publications give additional guidance on site safety: CIRIA R132 [1], BDA Guidance [2], HSE publication HSG47 [3], AGS guidance [4] and Coal Authority et al., 2012 [5].

Training should be given to ensure that personnel understand the necessary safety precautions.

Personnel should be provided with suitable protective equipment, taking into account the potential toxicity and other hazards anticipated (assumed or measured).

**WARNING.** Some persons are allergic/sensitive to traces of some gases and are liable to collapse and require assistance if affected. Although unlikely, the work should be conducted with this possibility in mind. This warning refers to work in the open and should not be confused with the requirements for work in enclosed spaces.

*NOTE 2 Carbon dioxide and some organic pollutants in the gas phase in soil and sub-soil can present toxicological risks of varying severity. Methane, hydrogen sulfide and some volatile organic compounds (VOCs) can form explosive mixtures with air.<sup>4)</sup> Large concentrations of carbon dioxide (in addition to being toxic) and methane can cause asphyxiation due to the associated reduction in oxygen concentrations. Oxygen concentrations in the ground can also be dangerously low in the absence of elevated carbon dioxide or methane concentrations.*

*NOTE 3 Injudicious choice of drilling method can cause risks to drillers due to gas coming out of boreholes. It could also cause risks to the public (e.g. the occupants and users of neighbouring buildings due to displacement of gas from the location where drilling is taking place and the creation of explosive atmospheres in the local drilling area).*

*NOTE 4 A number of serious incidents have occurred as a result of surface emissions of toxic gases into occupied properties during the investigation and treatment of nearby former coal mine workings. Of particular concern are incidents where carbon monoxide has been measured or inferred as entering occupied properties from the mine workings below. Mine workings can also contain methane, hydrogen sulfide, carbon dioxide and oxygen-deficient-air, all of which can be hazardous to health if emitted at the surface. Coal Authority et al., 2012 [5] gives guidance on the general procedures to be adopted when drilling or piling into former coal mine workings (including mine entries) and unworked coal. Prior to carrying out works that have the potential to intersect or disturb Coal Authority property, the Coal Authority request that their permission for the proposed works is obtained in accordance with their permitting procedure.<sup>5)</sup>*

### 5.3 Utilities

The location and route of all current and historical underground utilities should be ascertained in accordance with PAS 128; a similar search should also be made for above ground services.

## 6 Personnel for ground investigations

### 6.1 General

Personnel involved in carrying out a ground investigation should have suitable qualifications, skills and specialist experience in ground investigations generally. They should also be familiar with the purposes of the particular investigation and be suitably skilled and experienced in the specific methods of investigation required.

*NOTE A guide to the qualifications required for the various levels of seniority is given in Effective site investigation [6].*

### 6.2 Direction, planning and execution of an investigation

#### COMMENTARY ON 6.2

*Attention is drawn to the Construction (Design and Management) Regulations 2015 [7].*

<sup>4)</sup> For further information and guidance, see [http://www.safetydirectory.com/hazardous\\_substances/hydrogen\\_sulfide/fact\\_sheet.htm](http://www.safetydirectory.com/hazardous_substances/hydrogen_sulfide/fact_sheet.htm) [last viewed 24 June 2015].

<sup>5)</sup> See [www.coal.decc.gov.uk](http://www.coal.decc.gov.uk) [last viewed 24 June 2015].

For all projects where more than one contractor is involved (the majority of contracts involve more than one contractor at some stage), the client should appoint a principal designer who is responsible for coordinating the pre-construction phase of the works and ongoing design. The client is responsible for ensuring the principal designer is competent to carry out the works and is adequately resourced. There is likely to be a wide range of designers for the design, planning and execution of the project – all of whom should coordinate with the principal designer.

*NOTE 1 The principal designer might be a chartered engineer, structural engineer, architect or, on simple projects, the principal contractor and they might not have specialist expertise in geotechnics and/or geology.*

A geotechnical adviser should be appointed who is directly responsible to the principal designer for the planning, direction, execution and supervision of the ground investigation. More than one adviser may be appointed to take responsibility for different parts of the investigation because, for example:

- a) the scoping, planning and design of the investigation might be separated from the execution and supervision by contractual arrangements; and/or
- b) expertise might be required for a range of disciplines such as geology, engineering geology, geotechnical engineering, geophysics, hydrogeology and contaminated land.

The geotechnical adviser(s) should be suitably qualified and experienced.

*NOTE 2 It might be advisable for the geotechnical adviser to be registered with the UK Register of Ground Engineering Professionals (RoGEP) or similar as a means of demonstrating their ground engineering competences (see Effective site investigation [6]). There are three grades of registrant in RoGEP and it could be implied that a Registered Ground Engineering Professional would suffice for a relatively simple investigation whereas Specialist and Adviser grades are more appropriate as the complexity increases.*

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

The person responsible to the geotechnical adviser for the execution of the ground investigation might be on the staff of the geotechnical adviser, or might be a geotechnical consultant or contractor; they should be a suitably qualified geotechnical specialist, as required by the character and scope of the ground investigation.

### 6.3 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 practitioner.

*NOTE This person (referred to as the "investigation supervisor" in UK Specification for Ground Investigation [8] or the "responsible expert" in BS 22475-2) might be assisted by, or delegate this responsibility to:*

- a) *assistant geotechnical engineers or engineering geologists;*
- b) *field engineers and senior field technicians who are skilled in the work described in 6.7 and who are competent to supervise such work by others, and in addition might be required to supervise work described in 6.8.1 and 6.8.2;*
- c) *geophysical experts who are skilled in the work described in Section 5, and who are competent to supervise such work by others;*

- d) *drilling supervisors who are skilled in the work described in 6.8.1 and who are competent to supervise such work by others, and to supervise the work described in 6.8.2.*

#### 6.4 Logging excavations and boreholes and describing soils and rocks

Detailed descriptions for engineering purposes 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; these engineering descriptions are incorporated in the field logs to form part of the report preparation.

For more extensive investigations, it is preferable for this work to be carried out on site, and proper facilities should be provided. However, for smaller investigations, the description may be made at the premises of the ground investigation contractor or at another suitable location.

*NOTE For rotary cored boreholes, it might sometimes be necessary to have the full-time attendance on site of an engineering geologist so that the rock cores can be logged and described in their fresh condition as the work proceeds.*

The qualified operator, who is commonly the lead driller, should be responsible for recording the information obtained from the borehole as it arises (see 6.8.1 and BS 22475-2); this should include a measured record of strata, with simple soil and rock descriptions.

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.

#### 6.5 Laboratory work

The testing of soil and rock samples should be carried out in a laboratory approved by the client's geotechnical advisor, under the control of a suitably qualified and experienced supervisor. Laboratory technicians should have received training and/or have experience of the type of test they are conducting.

The laboratory chosen should be competent to carry out the testing and analyses required by the test methods. Laboratories are accredited for each test and this should be checked as required (see Foreword).

*NOTE It is desirable that the laboratory participates in external proficiency testing schemes, as available, relevant to the work being commissioned; see the AGS website<sup>6)</sup>.*

#### 6.6 Interpretation

##### COMMENTARY ON 6.6

*The preparation of the report, including the factual information obtained and the engineering interpretation of the data in the report, is described in Section 10.*

The report should be prepared by suitably qualified and experienced persons (see 6.2b) under the supervision of the geotechnical adviser.

#### 6.7 Field technicians

Field technicians who carry out sampling and testing in boreholes and probing (see Section 4), geophysical data acquisition (see Section 5), field tests (see Section 7) and instrument installations (see Section 8) should be suitably qualified and experienced in the work.

<sup>6)</sup> See <<http://www.ags.org.uk>> [last viewed 24 June 2015].

## 6.8 Operatives

### 6.8.1 Lead driller and driller (support operative)

There should be a lead driller in charge of each individual drilling rig, who should be skilled in the practice of exploration of the ground by means of boreholes, sampling and in-situ testing, in making groundwater observations in boreholes, and properly recording the information obtained.

*NOTE 1 The qualification criteria for personnel is given in BS 22475-2.*

*NOTE 2 It is advisable that all lead drillers employed on the contract hold a valid audit card of competence applicable to the work and the specific drilling operation (e.g. dynamic sampling, cable percussion, rotary) on which they are engaged, as issued by the British Drilling Association or an equivalent body. It is also advisable that they hold a Construction Skills Certification Scheme (CSCS) blue skilled (Land Drilling) card and that drillers who are support operatives to the lead driller hold an appropriate, valid and current audit card of competence and a blue skilled (Land Drilling) CSCS card.*

### 6.8.2 Operators of the excavating plant and ancillary plant

Operators of the excavating plant should be skilled and experienced in its safe use for digging trial pits and trenches.

*NOTE 1 It is advisable that operators hold a valid and current Construction Plant Competence Scheme (CPCS) card for the category of excavating plant being used.*

Support of excavations should be designed by competent persons and installed by suitably skilled operatives. The appointment of a temporary works coordinator is strongly advised.

*NOTE 2 It is advisable that operators of other plants listed as a CPCS category hold a valid and current CPCS card.*

## 7 Investigation strategy

The extent of the investigation should reflect the magnitude and nature of the proposed works and the nature of the site in terms of any risks that the ground or groundwater pose to the construction. The former use of a site and the presence of contamination of the ground or groundwater should also be considered as they can have a significant impact on the extent and nature of the investigation.

A risk register should be started at the earliest phase of any investigation. This risk register should identify the risks that the ground conditions could pose to the proposed construction project and should be continually maintained, updated and reviewed as the results of the investigation become available.

A ground investigation should proceed in phases as follows:

- Phase 1: Desk study and field reconnaissance (see Section 2);
- Phase 2: Preliminary investigation;
- Phase 3: Detailed (design) investigation;
- Phase 4: Control investigation; construction review, including any follow-up investigations during construction, and the appraisal of performances (see Section 11).

*NOTE 1 Phases 2 and 3 can be conducted together and can comprise one or more phases of investigation including sampling and testing, topographic and hydrographic surveying and any special studies (see Section 3 to Section 9).*

*NOTE 2 It is important to recognize that the terminology used in other contexts and by other professionals might differ from that used in this British Standard. For example, BS 10175 and BS 8576 use "preliminary investigation" to encompass "desk study and field reconnaissance" and "exploratory investigation" for what is described here as "preliminary investigation".*

Phase 1 should be undertaken at the start of every investigation. The desk study should take into account the possible existence of contaminated ground (where additional site safety procedures need to be established in advance of any field reconnaissance or intrusive investigation). The desk study should also include archeological, environmental and ecological considerations, which might impose constraints on the execution of Phase 2 and Phase 3. As far as possible, the assembly of the desk study information should be complete before the ground investigation (Phase 2 and Phase 3) begins. The field reconnaissance should also be carried out towards the end of the desk study and before any investigation activity on the site. The field reconnaissance should be carried out by suitably experienced personnel who are aware of the findings of the desk study and of the proposed works.

A preliminary ground investigation might often be desirable to determine the extent and nature of the main ground investigation; the scope of this investigation should follow the guidance in Clause 17.

*NOTE 3 The costs of a ground investigation are low in relation to the overall cost of a project and can be further reduced or can improve project outcomes by intelligent forward planning. Discussion at all phases with a geotechnical advisor or appropriate specialist can be used to formulate an efficient and economic plan for the investigations.*

In view of the possibility that the construction of new works could affect or be affected by adjacent property or interests, investigations for new works should consider all factors that might 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 to existing structures or the environment is a possibility, adequate photographic records should be obtained.

## 8 Planning and control of investigations

All relevant information collected from the sources discussed in Section 2 should be considered to form a preliminary model of the ground conditions and the engineering problems that might be involved before commencing the ground investigation.

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 new information. On many occasions, especially on large or extended sites, a preliminary investigation should be carried out, in order that the design and other investigations might be planned to best advantage. It might also be necessary to carry out phased investigations after the main work to gather more detailed information related to specific matters. These additional investigations could be carried out before or during the construction works and should be guided by the uncertainties identified within the current ground model.

The ground investigation should be completed to the extent of allowing economic design to be made and with the risks of unknown ground conditions having been reduced to an acceptable level before design is completed and the works start; the level of acceptability is a matter for discussion between the geotechnical advisor, the designer and the client. Sufficient time for ground investigation, including testing, reporting, interpretation and monitoring, should be allowed in the overall programme for any scheme. Changes in the project occurring after completion of the main investigation might require additional ground investigation; the programme should be adjusted to allow for this.

The need for additional investigation after the works commence should also be taken into account. In tunnelling, for example, probing ahead of the face might be required to give warning of hazards or changes in ground conditions. The properties of the ground and also the groundwater levels can vary with the seasons; in planning the investigation, the ground conditions at other times of the year should be taken into account.

*NOTE 1 The imposition of limitations (for reasons of cost and time) on the amount of ground investigation to be undertaken might 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 can prove more costly and result in delays.*

Adequate direction and supervision of the work should be provided by a competent person who has suitable knowledge, training and experience and the authority to decide on variations to the ground investigation (see Clause 6).

*NOTE 2 Further guidance on planning a ground investigation is found in Effective site investigation [6].*

## 9 Quality management

A quality management plan should be prepared and implemented to ensure that the results of the ground investigation are submitted within the required standards for accuracy and presentation, as defined in national standards, the contract and the specification.

The quality management plan should include written procedures covering some or all of the following components of a ground 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.

*NOTE These checks can be specific to a particular ground investigation or could be covered by the annual third party audit carried out in accordance with BS 22475-3.*

Management of geotechnical data produced from the ground investigation should be as described in BS 8574.

## Section 2: Desk study and field reconnaissance

### 10 General

The desk study and field reconnaissance should be carried out as the first stage of an investigation to enable an initial ground model to be developed, based upon the available information, and to plan the scope of the initial and subsequent stages of the investigation. A desk study and field reconnaissance should be carried out before a ground investigation programme is designed in accordance with the sequence specified in BS EN 1997-2:2007, 2.1.

*NOTE 1 Field reconnaissance has historically been referred to as site inspections, walkover surveys, site visits, etc.*

The desk study (or preliminary sources study as it is sometimes referred to) should identify the likely ground-related hazards which inform the initial project risk register. Subsequent phases of the investigative process should take into account these hazards in relation to the proposed development and should quantify, address and attempt to mitigate the risks associated with each hazard.

From the outset, knowledge of planning application status and conditions including discharge requirements should be identified.

The field reconnaissance should be carried out once the factual information for the site and its environs has been compiled and preliminary proposals for any ground investigation prepared.

*NOTE 2 Additional information on the geology and hydrogeology and potential construction and access constraints for ground investigation might be revealed by the field reconnaissance.*

Interpretation should be carried out as a continuous process, starting in the preliminary stages of data and information collection with the construction of the initial ground model. Further interpretation of the ground and groundwater conditions should proceed as information from the investigation, for example the ongoing desk studies and field reconnaissance, becomes available (by using this information it is often possible to detect and resolve anomalies as work progresses). At all stages the current version of the ground model should be used to identify the known/unknown information and so formulate the questions that need to be addressed by the next phase of study or investigation. The progressive resolution of these questions should be the aim of the investigation, although it is also usual for new questions to arise as more becomes known about the site.

*NOTE 3 A robust ground model, which is then interrogated and developed through the whole investigation process, is critical to the success of a ground investigation. By identifying the uncertainties in the knowledge of the ground and groundwater conditions sensible decisions can be made as to the need for further investigation, including additional intrusive investigation, examination of exposures within the construction or by monitoring of the structure during its construction and operation.*

The engineering design and construction proposals should also be taken into account along with the ground model as data and information becomes available, so that the geotechnical adviser can decide either what additional exploration and testing needs to be carried out or, where appropriate, what reductions in the original programme/scope are possible.

*NOTE 4 BS 10175 gives guidance on the design and execution of preliminary investigations (desk study and field reconnaissance, as well as preliminary risk assessment) for potentially contaminated sites and sites where there might be naturally elevated concentrations of potentially hazardous substances. This guidance is supplemented by additional guidance in BS 8576 for sites where there might be elevated concentrations of hazardous ground gases.*



The results of all studies and surveys should be formally presented in a report, bringing together details of:

- site topography;
- geology, hydrogeology and geomorphology;
- ground and groundwater conditions;
- preliminary geotechnical parameters;
- potential geotechnical problems;
- previous and existing uses of the site;
- services/utilities at the site (see **19.2.4**);
- anticipated construction hazards; and
- the proposed ground investigation.

*NOTE 5 High risk areas have been defined where development is likely to be affected by hazards from historical coal mining. Sites which fall within these areas require the submission of a Coal Mine Risk Assessment (CMRA) as part of their Planning Application. This assessment needs to be obtained if completed by others, or produced by the responsible expert prior to any investigation being planned. To determine if a site requires such a risk assessment, an online interactive map can be viewed via a link from <<https://www.gov.uk/planning-applications-coal-mining-risk-assessments>> [last viewed 24 June 2015].*

## 11 Desk study

The desk study should comprise a factual core supplemented by interpretative elements which summarize physical, geoenvironmental and geotechnical aspects in order to aid the formulation of a ground model or a conceptual site model. The successive stages of assessment and investigation should identify potential geotechnical, environmental and health and safety issues that are likely to detrimentally affect the site, its investigation and its development.

*NOTE 1 The typical scope of the factual core of the desk study is presented in Table 1 while those typical geotechnical aspects requiring further consideration are summarized in Table 2. An example format for such a report is given in Design manual for roads and bridges, Vol 4 [9].*

*NOTE 2 Annex B outlines the kinds of information that might routinely be needed for a desk study. Where there is a choice of site, information obtained from this study could well influence such choice. Much information might already be available about a site in existing records. A summary of the most important sources of information is given in Annex C; a more detailed catalogue is given elsewhere (see Perry and West, TRL Report 192 [10]).*

*NOTE 3 For most projects, the design and planning of construction requires a detailed examination of the site and its surroundings (a CIRIA project to develop guidance covering all the key stages in the planning and set-up of a construction site was underway at the time of publication of this British Standard). See Annex D. This examination might necessitate a detailed land survey (see **D.2**), or an investigation of liability to flooding. The investigation of ground conditions is dealt with in other sections of this British Standard, e.g. Section 3. Other subjects might be studied, such as unexploded ordnance (see **D.5**), hydrography (see **D.6**); climate (see **D.7**); hydrology (see **D.8**); sources of materials (see **D.9**); disposal of waste materials (see **D.10**); and other environmental and ecological considerations as appropriate.*

Table 1 Desk study: Typical factual core

| Aspect       | Typical details   |
|--------------|---|
| Site details | Location (address, grid reference); boundaries; land ownership; present/proposed land use; site protection and environmental status; topography, services/utilities and other relevant information.   |
| Site history | Review of historical maps, photographs, remote sensed images (aerial photographs and satellite imagery) and documents to determine past site usage. Identification of changes in topography and unstable ground; the presence of watercourses and potential for flooding; archaeological potential; the presence of Designated Heritage Assets (World Heritage Sites and their Buffer Zones, Listed Buildings, Scheduled Monuments, Areas of Archaeological Importance, Protected Wreck Sites, Registered Parks and Gardens, Registered Battlefields and Conservation Areas), man-made structures including foundations, infrastructure (e.g. tunnels, pipes, cables) and mine workings; the potential for contamination given current/past uses of the site. |
| Site geology | Review of all available geological, geomorphological and hydrogeological maps and memoirs, reports and other documents including digital data; exploratory hole record sheets and well records; past ground investigations in the vicinity.   |

*NOTE* The above list is non-exhaustive and other searches might be required for such things as utilities, invasive weeds, biocontamination (e.g. anthrax).

Table 2 Desk study: Typical interpretative elements

| Element                         | Typical details  |
|---------------------------------|--|
| Ground-related site constraints | Cataloguing of the identified site-specific factors that might affect the ground investigation and subsequent development proposals.   |
| Ground-related hazards          | Listing, describing and prioritizing the identified ground hazards (both site- and project-specific) together with proposals for further investigation and subsequent mitigation. Ground hazards can be topographic, geological, hydrogeological and man-made. Assessment of the information available for reliability and completeness in terms of identifying all sensibly possible hazards. |
| Ground investigation            | Recommendations for the scope of the ground investigation required; specific site/project-specific issues identified which require particular investigation.   |

Where mining and quarrying, whether past, present or prospective, is likely to be a factor affecting the site, reference should be made to Annex C. Where contamination of the ground or the presence of ground gases is possible, reference should be made to BS 10175 and BS 8576.

Local sources of information should also be referred to, including:

- local authorities and local/regional statutory undertakers (for example, Engineer's and Surveyor's Offices) for earlier uses of the site and the results of excavations in the area;
- repositories of information on previous investigations on or near the site;

- repositories of information on local industry, commercial premises and land uses;
- museums and libraries for historical maps, photographs, etc;
- local press publications;
- professional or amateur societies' journals, papers and other publications; and
- local oral tradition (although of variable reliability) and information.

*NOTE 4 It is possible to purchase reports from a number of private companies that provide a collation of some of the available information relevant to a site's history, geology, hydrogeology and environmental setting, etc. Although very helpful, these are not sufficient on their own to fully characterize a site. It is important to cross-check information from the various sources as there might be errors in the data banks from which they are derived (e.g. they might not be up-to-date) or they might be incomplete, not site-specific or insufficient for the project.*

## 12 Field reconnaissance

A thorough visual examination should be made of the site to confirm, amplify and supplement the available findings of the desk study. All the information compiled about the site should be reviewed thoroughly before the field reconnaissance is undertaken, allowing a greater understanding of the significance of the features subsequently observed within and around the site. The reconnaissance should encompass the areas surrounding the site; the extent and coverage of these off-site observations is a matter of judgement.

*NOTE 1 Annex E gives a summary of the procedure for field reconnaissance and the main points to be routinely considered. This procedure might need to be extended or modified, depending upon the particular circumstances of the site.*

The following preparations should be made before carrying out field reconnaissance:

- a) a site plan, district maps or charts, and geological maps and aerial photographs and satellite imagery should be obtained as available;
- b) permission to gain access should be obtained from both owner and occupier as necessary; and
- c) where evidence is lacking at the site or some verification is needed on a particular matter, for example, flood levels or details of changes in site levels, reference should be made to sources of local information (see Annex C).

A health and safety risk assessment should be carried out before the visit. This assessment should be based on the results of the desk study and should be updated as the reconnaissance proceeds to take account of what is seen on site. If the presence of potentially hazardous substances is suspected (e.g. contamination), the risk assessment should be reviewed and appropriate control measures should be taken, which might necessitate the use of personal protective equipment. Specialist advice should be sought as necessary. Personnel undertaking the visit should be briefed on the hazards that could be encountered and the precautions to be taken.

*NOTE 2 Information about the nearby area can include:*

- *natural or man-made exposures such as cliffs, quarries or pits, railway or road cuttings can reveal soil and rock types and their stability characteristics;*
- *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 reconnaissance is the presence of current or old mine workings (see Annex F) or other underground excavations, such as old cellars, tunnels or sewers; and*
- *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 could be significant.*

The type and abundance of vegetation on a site should be noted and can provide information on the groundwater conditions, chemical contamination of the ground, or the presence of ground gases (see BS 10175 and BS 8576). The presence of protected and/or invasive or injurious species should be noted (see 19.2.6).

If during the visit anything is seen that is deemed likely to pose an immediate threat to human health and safety or the environment, this should be reported to whoever is in control of the site so that any required action can be taken.

## 13 Earlier uses and state of site

### 13.1 General

If a site has been used for other purposes in the past, this can have a major effect on the proposed intended use; therefore, a careful visual inspection of a site, including the vegetation it sustains, should be carried out. This might reveal clues suggesting interference with the natural subsoil conditions at some time in the past.

A study of maps and information from all available dates and sources should be undertaken.

*NOTE 1 The former uses of a site can sometimes be determined from such a study, which could include examination of aerial photographs, and could be carried out in tandem with an archaeological study. In some cases, the forerunners of local authorities commissioned the making of maps of their areas long before Ordnance Survey maps were produced, and these maps were often drawn in the most meticulous detail.*

Former occupiers of the site should also be consulted, as they might be able to provide detailed information indicating the layout of facilities. The courses of former drainage systems should be identified.

*NOTE 2 There might be several years between the survey date and the publication date of some OS maps. In addition, because of the potentially large intervals between surveys, activities can occur in an area (e.g. formation and filling of a pit) without it being recorded on an OS map.*

*NOTE 3 In the marine environment to high tide or where topographic changes can occur more rapidly, references to early Admiralty charts and other charts might indicate earlier configurations, see C.4.*

### 13.2 Tunnels and underground structures

Where the presence of tunnels or underground structures are a possibility, they should be taken into account. It should not be assumed that they are all shown on Ordnance Survey mapping. Information from transport and services/utility infrastructure owners should be requested as needed.

### 13.3 Underground mining

Annex F gives details of the procedure that should be followed when carrying out enquiries and the subsequent ground investigation for an area where underground mining has been or is currently being carried out or planned.

Potential liabilities and ownership issues should be considered when planning ground investigations in areas potentially containing voids. Permission from the mineral and land owner should be obtained before any ground investigations are carried out; it is common practice for such investigations to be carried out in accordance with a licence or permit which places certain rights and responsibilities on each party, e.g. the Coal Authority.<sup>7)</sup> The responsible expert specifying the investigation should take responsibility for completing the application, obtaining the permit and ensuring thereafter compliance with the permitting requirements.

*NOTE 1 The United Kingdom Health and Safety Executive also requires prior notification of certain ground investigation activities proposed within mining areas.*

*NOTE 2 Mining has been used to recover a range of materials including coal and minerals as well as construction and agricultural materials such as building and roofing stone, sand, clay, flint and chalk.*

### 13.4 Quarries and opencast mines

Relevant sources of information should be consulted regarding the quarrying of materials such as building stone, chalk, sand, gravel and clay, which has been carried out since ancient times. Over the years, many excavations have been backfilled and then put to some other use; many such sites have subsequently been used for waste disposal (see BS 10175 and BS 8576).

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 C; the relevant records should be consulted.

Other minerals have also been extracted by opencast methods. The relevant records should be consulted.

### 13.5 Waste tips and landfills

#### COMMENTARY ON 13.5

*The site under investigation might 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 ground investigation personnel and protection of the environment.*

It should normally be assumed that harmful chemicals and toxic or explosive gases are present. The Environment Agency in England, the Scottish Environmental Protection Agency, Natural Resources Wales, and Northern Ireland Environment Agency should be consulted, as appropriate, during the planning stage of investigations at such sites (see also BS 10175 and BS 8576).

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<sup>7)</sup> Prior to carrying out works which have the potential to intersect or disturb Coal Authority property, the Coal Authority request that their permission for the proposed works is obtained in accordance with their permitting procedure, see <[www.gov.uk/government/organisations/the-coal-authority](http://www.gov.uk/government/organisations/the-coal-authority)> [last viewed 24 June 2015].

## 13.6 Industrial sites

### COMMENTARY ON 13.6

*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 might be foundations including piles and sheet piled walls, engine beds, pits, chambers, and underground storage tanks, often of massive construction, which can be major obstacles to redevelopment. The ground might still be affected by extremes of temperature from installations such as cold-storage plants, or 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 material. Historical aerial photography can be very useful in identifying the locations of physical obstructions and potential chemical contamination. Other sources of evidence might be identified by archaeological desk-based assessments.*

Planning and building control records can be a useful source of detailed plans of the site including the location of underground tanks and services; such records should be consulted.

*NOTE Care is required when using plans derived from planning and building control records as they do not always accurately show the “as built” layouts.*

## 13.7 Monuments and archaeological remains

If it becomes apparent during the desk study that any Designated or non-Designated Historical Asset is likely to be affected by the investigation or subsequent works and if this has not already been noted in an archaeological study conducted as part of the same project, then the project’s archaeological consultant or contractor, if such have been appointed, should be notified. If no such appointment has been made, the matter should be referred to the relevant local (Local Planning Authority) or national (English Heritage, Cadw, Historic Scotland or DOE Northern Ireland) authority as appropriate.

## 13.8 Ecology

Ecological issues should be carefully taken into account, because they could impose significant constraints on both the execution of the ground investigation and on the future development of the site.

*NOTE Many plants, animals and habitats are specially protected by law. Attention is drawn to the Conservation (National Habitats, etc.) Regulations 1994 [11].*

# 14 Aerial photographs and satellite imagery

## 14.1 General

### COMMENTARY ON 14.1

*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. Panchromatic aerial photographs, together with infrared, microwave, multispectral and hyperspectral data from a range of aircraft and satellites might be available. Derived value-added-products, which were once seen as experimental, such as ground displacement maps from interferometry (e.g. InSAR [Interferometric Synthetic Aperture Radar]) can also provide practical information on ground conditions. Archives of imagery can be used to “look back in time” and gain a baseline that might otherwise not be available.*

*Remote sensing imagery is particularly useful for mapping large, undeveloped sites, notably for projects such as dams, power stations, and highways, although they can also be used for mapping smaller sites with the advent of Very High Resolution (VHR) satellite imagery and data from Remotely Piloted Aerial Vehicles (RPAVs), sometimes also referred to as Unmanned Aerial Vehicles (UAVs). A specialist organization in Earth Observation (EO) can recommend the correct type and scale of data for a particular application.*

During the desk study phase, remotely sensed imagery 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. In the UK, a considerable database of aerial photography has been available since the 1940s, particularly in urban areas, and existing sources should be checked in the first instance (see C.7). Although a non-specialist can often extract a substantial amount of relevant information from aerial photography and satellite imagery, trained interpreters should be used if full information is to be obtained. Interpreters should be carefully briefed on the requirements of the interpretation.

*NOTE The first stage is often to consult an online repository of imagery, such as NASA's Whirlwind. A professional license is required for commercial work and the imagery in these repositories is not always accurately geo-located. If required, additional imagery from aircraft or satellite can be acquired and processed by a specialist organization. Derived outputs can include orthophotographs, thermal images, ground displacement maps and elevation models.*

## 14.2 Topographical mapping

Accurate, contoured maps can be produced from aerial photographs by competent survey organizations. Ground control should be provided by placing markers on the ground that can be identified from the air and also measured in plan and level on the ground and/or by GPS (Global Positioning Systems) ground control. Methods are available to make a surface ground model from overlapping aerial photographs that contain markers of known positions (easting, northing and altitude, i.e. x, y and z).

The scale of photography should be properly related to the project.

*NOTE 1 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 for 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. Commercial companies and other organizations (e.g. the UK Government Environment Agency) undertake aerial surveys and are a source of archive data that can be bought off-the-shelf or new surveys commissioned. This is a situation that is changing with the increasing availability of RPAVs and UAVs.*

*NOTE 2 Digital Elevation Model (DEM) datasets are available from a range of sources and at different resolutions and formats. The choice of dataset depends on the available data and project requirements and can include Digital Terrain Model (DTM), i.e. bare-earth terrain, or Digital Surface Model (DSM), including vegetation canopy and/or buildings. The definitions of DEM, DTM and DSM vary – often according to data originator and end-user requirements. For example, urban modellers typically prefer to work with DSMs that include building structures without vegetation canopy, whilst foresters might need DSM to show the vegetation canopy. Embankments and bridges can be retained or omitted in some DSM datasets depending on the end user requirements and data supplier.*

*NOTE 3 Aerial photography requires orthorectification to remove distortions and be sufficiently accurate for use in Geographic Information Systems (GIS) and other software. Orthophotograph raster images can be utilized in GIS to be map-ready and can be combined with other digital datasets, including DEM for 3D visualization.*

### 14.3 Identification of features

#### COMMENTARY ON 14.3

*Remotely sensed images can often be used to identify features of engineering significance such 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.*

Remotely sensed images are particularly useful in the study of extended sites where ground visibility is limited by obstructions or where access is difficult; however, significant features should be checked on the ground whenever possible.

*NOTE Although photographs are best studied stereoscopically (in 3D), much data can be obtained from single (mono) photographs (both vertical and oblique). 3D interpretation using mirror-stereoscope or image processing software allows for greater detail to be derived from the imagery, particularly useful for geomorphological analysis or for site history assessment (e.g. assessing stages of quarry backfill and identifying characteristics of made ground). Additional information can 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 or different tidal conditions pertain at a site.*

### 14.4 Earlier uses of sites

Historical aerial photography should be inspected, as it can yield valuable information about previous construction and earthworks on a site, and is an essential part of the desk study of former industrial, quarrying and waste tip sites.

*NOTE The RAF carried out extensive photography in the early 1940s and many areas of the UK have been subject to repeated photography by commercial sources since that date. Annex C gives details of sources of historical aerial photography, and BS 10175 and BS 8576 describe particular features of importance to be noted on potentially contaminated sites.*

### 14.5 Sophisticated techniques

#### COMMENTARY ON 14.5

*The majority of pre-1980s archive air photography is panchromatic (black and white). Naturacolour (true colour RGB) and false colour can offer particular advantages. Multispectral techniques providing simultaneous images in selective wave bands, including the infrared, are also available. One example of the uses of infrared 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. Thermal aerial photography can be beneficial for distinction between materials, landfill site assessments and for urban modelling. It is stressed that the more sophisticated, and costly, systems require more highly trained interpreters if their full value is to be realized. Rapid advances are being made in the use of sensor systems, in the conventional airborne field (fixed wing and helicopter), unmanned aerial vehicles (UAVs) and satellite imagery.*

Remotely sensed data from a range of sources is available or can be flown and should be used where appropriate (for example, high resolution, LiDAR (Light Detecting and Ranging) and multispectral data).

*NOTE 1 There is a need to know and understand when and how remotely sensed data was collected. It is not a substitute for field reconnaissance.*

*NOTE 2 High resolution satellite imagery can be used for acquiring base imagery (orthoimagery) and for DEM generation.*



*NOTE 3 LiDAR provides detailed 3D data that can be supplied in different formats for use in topographic analysis. LiDAR can be airborne (fixed wing or helicopter) or terrestrial (tripod or mobile) and is widely utilized for earthworks assessment (roads and railways), coastal studies and city modelling. Existing archive LiDAR data is available from commercial and government archive sources or can be commissioned. LiDAR surveys or terrestrial photogrammetry can be used for building surveys (external and internal) and monitoring of structures (facades, embankments, dams, etc.).*

*NOTE 4 Multispectral and hyperspectral data can be used to measure and map spectral differences of materials (bedrock, soils, vegetation and man-made objects). Radar imagery (satellite and airborne) is used to create DEM datasets at the detail and scale relating to the method. Airborne radar can produce more detailed, "site specific" data than satellite, which covers larger areas. Advanced data processing techniques for radar data, such as Interferometric Synthetic Aperture Radar (InSAR) allows for measuring surface deformation and can be of benefit for a range of applications, such as monitoring coal mining related subsidence and in some geographies is a useful tool for assessing earthquake and volcanic hazards (see Terrafirma<sup>8)</sup> – Pan-European Ground Motion Hazard Information Service).*

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<sup>8)</sup> <<http://www.terrafirma.eu.com/Terrafirma>> [last viewed 24 June 2015].

## Section 3: Planning ground investigations

### 15 Types of ground investigation

#### 15.1 Sites for new works

Investigations of sites for new works should aim to provide information to assist in the selection of the most suitable location for the works. They should also aim to provide the data required for designing the geotechnical aspects of the works.

*NOTE 1 The type of information required varies, depending on the nature of the proposed works.*

Where a building is to be constructed, for example, a knowledge of the subsurface strata and groundwater conditions should include:

- a) the strength of the various layers so that a stratum capable of supporting the loads imposed by the foundations can be identified;
- b) the stiffness of those strata which are subjected to an increase in stress to allow the magnitude of settlement to be assessed;
- c) the potential for shrinkage or swelling of clay soils due to weather, transpiration of trees and shrubs, and heat, for instance from furnaces;
- d) the potential for soil movements associated with freezing, which can occur naturally or artificially;
- e) the degree of aggressivity of the soil to materials that might be used for foundations or other buried elements of the works; and
- f) the presence and possible implications of and on vegetation, including damage by the investigation.

Where an excavation is required, the investigation should enable decisions to be made on:

- 1) how material is to be removed;
- 2) excavation stability and support requirement;
- 3) the groundwater conditions and any groundwater control or other requirements;
- 4) whether the excavated material has suitable engineering and chemical properties to be retained, reused and/or reinstated as part of the earthworks design, and whether the nature of the excavated material is likely to change, such as an increase in volume (bulking); and
- 5) whether any of the soil or groundwater contains hazardous substances, therefore requiring special controls on excavation, movement, disposal and additional safety measures.

Investigations should also take account of changes which can potentially be caused by the proposed new works, whatever their nature, for example:

- i) impeded drainage, which can result in a rise in the groundwater level; this can cause softening of fine grained 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 can result in ground heave;
- ii) alteration in stream flow of a waterway, which can cause undercutting of banks or scouring of foundations of walls, bridges and piers, and can be due to works carried out some distance away;

- iii) siltation of the approaches of harbour works or the changing of navigation channel alignments;
- iv) disturbance of contaminated ground, which can allow aggressive leachates or noxious gases to migrate through the ground or into the environment;
- v) environmental or ecological considerations that might impose any constraints on the scope of the new works; and
- vi) the compatibility of the environmental considerations with the geotechnical design.

For design purposes, assessments should be made of considerations such as bearing capacity and settlement of foundations, slope stability of 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, the range of conditions, including the least favourable conditions, should be known. Not only should a study be carried out of the degree of variability in the strata over the area of the site, but account should also be taken of the possible effects of groundwater variation and weather conditions on the properties of the various strata.

*NOTE 2 Where works require excavations into or within rock, the orientation and nature of discontinuities in the rock can be the most important factor.*

*NOTE 3 The requirements for investigations of extensions on or reuse of existing sites are in most respects similar to those above except that the location of the proposed works is already substantially known.*

## 15.2 Impact on existing structures

### COMMENTARY ON 15.2

*Existing structures close to, or even at a distance from, the proposed site might 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.*

The effect of new works on existing structures should be taken into account as part of the investigation process; possible changed conditions include the following:

- a) excavations or demolitions in the immediate vicinity, which could 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 could cause ground deformations and subsidence and the effect of tension and compression on the structures and drainage;
- c) stresses that the new structure might 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 can increase effective stress in the ground, which could cause damaging settlement of adjacent structures. Also, the design of a filter for wells so that any leaching of fines from the subsoil does not result in excessive settlement of structures, which might occur at a considerable distance from the well; and
- f) changes in groundwater temperature, for example, shallow geothermal systems.

Given problems of this kind, it should first be established what changes are likely to occur. Knowledge of the subsurface strata should be determined from the ground investigation and samples should be examined and tested to assess the effect that the changed conditions are likely to have on these strata.

*NOTE 1 Detailed analysis might be needed to estimate the effect of the changed conditions on the safety of the existing works.*

*NOTE 2 On occasions, existing structures are demolished but their foundations left intact and re-used to support a replacement structure. In these circumstances, an investigation would be tailored to the specific requirement (see Butcher, Powell and Skinner, 2006 [12] and CIRIA C653 [13]).*

### 15.3 Defects or failures of existing works

#### COMMENTARY ON 15.3

*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.*

Where a failure has occurred, observations and measurements of the structure should be carried out to determine the mode or mechanism of failure; these might suggest the origin of the trouble, or at least indicate whether the ground conditions were partly or wholly responsible. If this is the case, the ground investigation should ascertain the condition of the strata and the groundwater conditions, both as they exist in situ and, if possible, as they existed before the works were constructed. Each failure should be evaluated individually.

*NOTE 1 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.*

*NOTE 2 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 can be used to monitor potentially unstable conditions. These techniques are described in BS 6031 and Section 8.*

*NOTE 3 An investigation to determine the causes of a failure might be much more detailed than an investigation for new works.*

### 15.4 Material for construction purposes

#### COMMENTARY ON 15.4

*The investigation of a site might be required where the main objective is to establish whether it is a potential source of materials suitable for use in the construction of works elsewhere.*

Investigations of sites to identify materials for construction purposes should include the following, as necessary:

- a) assessment of the suitability and quantities of material that become available from excavations or dredgings for construction work and fills in other places, e.g. whether spoil from cuts can be used for embankments in roads and railway works;
- b) ascertaining the presence of suitable material for specific purposes, e.g. borrow pits for earthworks, aggregate for concrete and road construction (see BS EN 12620 or, where ecological or environmental impact is an issue, see BS ISO 15176);
- c) assessment of the chemical characteristics of ground that might need to be treated or removed to protect the environment;

- d) ascertaining the location of suitable storage or disposal sites for excess spoil, dredged materials and groundwater, for which attention is drawn to current waste management regulations; and
- e) assessment of the suitability of groundwater for use for construction purposes.

*NOTE* In works such as railways and roads, a prior knowledge of the strata on the line of the route might 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 might be possible to assess the suitability of the material by visual inspection. Otherwise, the suitability requires testing (field and/or laboratory) to identify the best use of the material (see Manual of contract documents for highway works, Vol. 1 [14]). Records of the British Geological Survey are recommended for investigations of this kind (see Section 2).

## 16 Geological mapping

The potential impact of the local geology on the project should be understood as a part of the investigation. Whatever information on local geology is obtained from published geological maps, memoirs and models or from commercially available extracts at the desk study stage (see Section 2), additional geological mapping or modelling should be carried out where appropriate (see C.2.1.1 for further guidance).

*NOTE* 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 might, therefore, require the mapping of a larger area.

An understanding of geomorphological features should inform the interpretation of the nature and distribution of soils and rocks. Hydrogeological conditions and man-made features should be recorded as part of the mapping.

Information from natural exposures and man-made exposures, such as quarries and cuttings beyond the site, might provide data on the material and mass characteristics, including, for example, the character of discontinuities, weathering profiles and the nature of the junction between soil and rock formations; such information should be used as a guide to conditions likely to be present at and beneath the site. Interpolation should be made with care and with knowledge of units and local geological conditions; geological deposits can vary laterally and very important geological structures such as faults and other major discontinuities might have only a restricted extent.

The information obtained from geological maps and mapping at all stages of the project should be used to assist with the formation and evolution of the ground model.

## 17 Scope of the ground investigation

### 17.1 General

#### *COMMENTARY ON 17.1*

A range of methods is available for use in ground investigations; these include non-intrusive methods, such as geophysical surveying (see Section 5) and intrusive methods, such as excavations and boreholes (see Section 4 and BS EN ISO 22475-1) and probing (see Section 7). The factors determining the selection of which method or methods is to be used in a particular investigation are discussed in Clause 19 and Clause 20. In general, the recommendations in 17.2 to 17.7 apply irrespective of the method adopted, and the term investigation point is used to describe a position where the ground is to be explored by any particular method.

Ground investigations and testing should be carried out in accordance with BS EN 1997-2 and BS EN 1997-1 and the related test standards cited therein.

The scope of the ground investigation should be determined by the character and variability of the ground and groundwater, the type of project (geotechnical category) and the amount and quality of existing information. The general character and variability of the ground should be established during the preliminary investigation before deciding on the basic principles of the design of the works undertaken for the design investigation; the desk study of existing information might provide sufficient high quality data for a preliminary design to be started with confidence.

*NOTE 1 BS EN 1997-2:2007, Annex B outlines the geotechnical investigation process through to use of the structure as well as the selection of different investigation methods. It also provides guidance on the spacing of investigation points for a variety of structures and the depths to which investigation are to be taken.*

*NOTE 2 Certain methods of investigation are more suitable than others on contaminated land (see BS 10175 and BS ISO 10381-2).*

Many ground investigations comprise both geotechnical and geoenvironmental aspects. When designing the scope of integrated investigations, the recommendations given in BS 10175 should be followed (see also 17.8 and 17.9).

### 17.2 Phased investigation

Following the desk study, a ground investigation should normally be performed in phases in accordance with BS EN 1997-2:2007, Section 2. These phases are preliminary investigation, design investigation, controlling and monitoring during construction; the first two investigation phases may be carried out in a single site visit.

The initial phase (preliminary investigation), which might involve widely spaced boreholes, probing or trial pits, should be designed to establish the general geological conditions, the suitability of different methods of investigation and the groundwater conditions.

*NOTE The preliminary investigation assists in the design of an effective programme for the detailed investigation. It might also provide an opportunity to take samples for chemical analysis to determine whether they are contaminated. However, such testing is not a substitute for a properly planned investigation for contamination (see 17.8 and 17.9).*

For more complex structures, the preliminary investigation should be followed by a more detailed (design) investigation.

Regardless of the number of phases of investigation, the designers should satisfy themselves that the scope of the investigation(s) provides sufficient data for economic and safe design and construction. Even so, further investigation and/or monitoring might be warranted during and after construction (see Section 11).

### 17.3 Geotechnical category

The investigation should be appropriate to the geotechnical category and should yield sufficient information on which to base a safe and economical design of the project; the categorization of structures is given in BS EN 1997-1 as follows:

- Category 1 – small simple structures with negligible risk;
- Category 2 – conventional structures with no exceptional risk; and
- Category 3 – large or unusual structures with abnormal risks.

The information from the investigation should be used 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 might be affected by the new works or their construction.

The scope of the investigation should be in accordance with BS EN 1997-2 as a minimum.

*NOTE Other investigation methods over and above these documents might be required as given in this British Standard and other sources.*

### 17.4 Character and variability of the ground

#### COMMENTARY ON 17.4

*Irrespective of the geotechnical category, 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 should usually be determined by the nature of the works proposed, but it might be necessary to explore to greater depths at a number of points to establish the overall geological structure and where hazards or changes in ground character can affect the structure during its design life. The technical development of the project should be kept under continuous review since decisions on the design influence the extent of the investigation.

*NOTE The detailed geology of a site can only be inferred from aerial photography, from surface outcrops and from subsurface information at the positions of the investigation 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 and risks; complete excavation is the only way to reveal the actual 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 from geophysical methods (see Section 5).*

### 17.5 Positioning of investigation points

The points of investigation, e.g. geophysical measurements, boreholes, probings, pits, sampling or measurements, should be so located that a general geological view of the whole site can be obtained, providing details of the engineering properties of the ground and of groundwater conditions. More detailed information should be obtained at positions of significant structures and earthworks, at positions of special engineering difficulty or importance and where ground conditions are complicated, e.g. suspected buried valleys, karstic features or landslide areas.

*NOTE Further guidance is given in BS EN 1997-2:2007, Section 2.*

In the absence of other criteria, a regular array of investigation points may be used in the design of an investigation. However, sufficiently close supervision and flexibility (in the programme and 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 kept under review accordingly. The use of geophysical mapping should be considered to interpolate between intrusive investigation points.

When investigating for proposed tunnels and shafts, boreholes should be offset so as not to interfere with subsequent construction or create pathways for groundwater. For other structures, the need to offset boreholes and trial excavations from critical points should be taken into account. Trial excavations should be outside proposed foundation areas.

For linear structures, such as highways, some investigation points should be arranged at offsets to the centre-line of the proposed road, so that lateral variation in ground conditions are revealed and material obtained to test suitability for use as fill material.

## 17.6 Investigation point spacing

Investigation points should be spaced in accordance with BS EN 1997-2:2007, Annex B, unless there is good reason not to do so, which might include the structure, experience and prior knowledge of the ground conditions.

*NOTE Additional rules for low rise buildings are given in BS 8004.*

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

## 17.7 Depth of exploration

### 17.7.1 General

The minimum depth of investigation points should be in accordance with BS EN 1997-2:2007, Annex B, unless there is good reason not to do so, which might include the structure, experience and prior knowledge of the ground conditions.

*NOTE 1 Additional rules for low rise buildings are given in BS 8004.*

The depth of exploration depends on how significantly new work affects the ground and groundwater, or is affected by them. For example, exploratory holes for a building should normally be taken down to a depth that includes all ground that might be stressed to a significant level by the foundation. This might include investigation of weaker strata overlain by a stronger layer.

If rock is encountered, the depth of penetration into the rock should be taken into account; this depends on several variables including the type of structure to be constructed and the anticipated ground conditions. Potential voids (either natural or man-made, see Annex F) should be taken into account in assessing the required depth of investigation.

*NOTE 2 It might also be necessary to advance more than one borehole by an appropriate method to penetrate sufficiently far into the "hard stratum" to establish whether bedrock or a boulder has been encountered, unless prior knowledge of the local geology obviates this.*



There are likely to be numerous combinations of geological strata that require the depths of investigation points to be reviewed on a project by project basis. No guidance can be given here for 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 17.7.2 to 17.7.8.

*NOTE 3 It is not always necessary that every exploration be taken to the depths recommended in 17.7.2 to 17.7.8. In many instances, it is adequate if one or more boreholes are taken to those depths at an early stage of the field work to establish the general ground profile, and then the remainder sunk to shallower depths to explore more thoroughly the zone near the surface which the initial exploration had shown to be most relevant to the problem in hand.*

Within strata of either low strength or high compressibility, within made ground, or within ground that has been weakened by the effects of mining and/or ground subsidence, the depth to base of this ground should be proven unless known from the latest ground model.

## 17.7.2 Foundations for structures

### 17.7.2.1 Spread foundations

For spread foundations, the depth of exploration should be in accordance with BS EN 1997-2. The depth of exploration should cover the zone of ground stressed by the foundations associated with the proposed structure(s); it is usually related to the width of the loaded area.

*NOTE 1 The factors relating thickness of zone to width of foundation are given in BS EN 1997-2:2007, Annex B.*

*NOTE 2 The exception to abiding by the depth/width relationship is where the imposed stress change becomes insignificant when compared with the strength and stiffness of the ground at a lesser depth, e.g. in competent rock.*

### 17.7.2.2 Piled foundations

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. Investigation depth for piled foundations should be in accordance with BS EN 1997-2: this would generally require that a conservative assumption of pile depths is made in scheduling the depths of investigation.

*NOTE 1 If the information from the investigation shows that deeper piles are required than previously assumed, additional investigation is likely to be appropriate.*

In addition, the following factors should be taken into account when planning the depth of exploration.

- a) Pile groups stress the ground below the pile points to a greater depth than 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.
- b) Made ground and compressible soils seldom contribute to the shaft resistance of a pile and might add down drag to the load on it. The whole pile load, possibly with the addition of down drag, should be borne by the stiffer strata below these materials.
- c) In the case of end-bearing piles in strong rock, boreholes should be of sufficient depth to establish conclusively the presence of suitable founding rock. The rock should then be further explored, usually by means of rotary

drilling, to such a depth that the geotechnical advisor is satisfied that there is no possibility of weaker strata occurring beneath, which could affect the performance of the piles.

- d) There are some instances where consideration should be given to shortening the investigation holes compared to the depths given in BS EN 1997-2:2007, Annex B. An example of this would be pile-supported rafts on clays which are being used solely to reduce settlement and where relatively incompressible strata occur within the zone of influence of the "imaginary raft". In this case, the depth of exploration is governed by the need to examine all strata that could contribute significantly to the settlement.
- e) In rocks, the exploration should be taken through the weathered materials and should penetrate a sufficient depth into the relatively unweathered rock to prove its continuity.

Based on the information of the ground model obtained from the desk study, the general guidance given in a) to e) and the assessment of the types of pile likely to be considered, the geotechnical advisor should determine the depth of exploration and be ready during the course of the field work to modify this depth as necessary.

*NOTE 2 If any structure requiring piled foundations is likely to be affected by subsidence due to mining or any other causes, greater exploration depths than those recommended in this clause might be required so that basic geological data can be obtained.*

### 17.7.3 Embankments

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

### 17.7.4 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 proposed slopes and the base of the excavation; this might necessitate proving the full depth of any relatively weak strata.

Groundwater conditions should be determined to ensure stability of the slopes and the base of the excavation for the design life.

### 17.7.5 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.

### 17.7.6 Pipelines

For deep pipelines, the depth of exploration should enable groundwater control to be designed if necessary and allow any likely difficulties in excavating trenches and supporting the pipelines to be investigated.

*NOTE Exploration to significant depths below the invert level might be advisable. Large pipelines, especially those in ground of low bearing capacity or slope instability, require special consideration.*

### 17.7.7 Maritime works

For maritime works, tidal variations should be taken into account, together with the appropriate considerations from 17.7.2 to 17.7.6.

### 17.7.8 Tunnels

For tunnels, the exploration should be taken to an adequate depth below the proposed invert level, both because changes in design might result in the lowering of the level of the tunnel, and because the zone of influence of the tunnel can be extended by the nature of the ground at a greater depth. Some of the boreholes should be taken to a depth sufficient to establish the overall geological structure (see 17.5 on the location of the boreholes).

An investigation point should be formed close to the location of any tunnel access shafts, portals, etc. In the case of access shafts, the depth of investigation should be sufficient to identify the potential for hydraulic uplift of the base and for any consequential cut off walls (temporary or permanent works) extending below shaft invert level.

## 17.8 Integrated investigations

### COMMENTARY ON 17.8

*The main source of guidance on investigation of potentially contaminated sites is BS 10175. However, it is common practice to run both geotechnical and contaminated land investigations together in an integrated investigation. Integrated investigations may also include investigations for ground gas or archaeological or other types of investigation.*

*Integration of ground investigations can often result in lower costs and greater efficiency when compared to undertaking separate field investigations owing to the following factors:*

- a) simplified project management;*
- b) common use of equipment and procedures;*
- c) exploratory holes can be used for more than one purpose;*
- d) joint health and safety procedures established and implemented;*
- e) joint environmental and/or archeological protection procedures established and implemented;*
- f) integrated consideration of resultant data; and*
- g) reduced project duration.*

*However, depending on the circumstances, site management operations might be more complicated, the sharing of resources could result in delays if not properly managed and increased activity on site might present safety issues.*

The degree of integration should be based upon the findings of the desk study and preliminary investigation. Integrated field investigations should be designed so that the requirements of each part of the investigation do not compromise any other part. For example, sampling locations for contamination should not be moved from a selected grid pattern (see BS 10175:2011+A1:2013, 7.7.2) in order to accommodate geotechnical requirements, which might necessitate additional investigation points.

*NOTE 1 Further information on integrated investigations is provided in Annex G.*

Samples that might be contaminated or contain chemical or physical hazards should be identified on site; this is informed by the desk study and the findings on site.

*NOTE 2 Identification of hazards on site is the preferred approach so that appropriate geotechnical test samples are sent to the geotechnical laboratory. However, the alternative is that the geotechnical laboratory manager is made fully aware of the situation before the laboratory consents to receive the samples and as part of the project contract prior to hazardous material testing.*

The assessment of the hazard should be carried out by a laboratory specializing in the type of testing which is appropriate to the nature of the likely hazard. The findings should be used by the geotechnical laboratory supervisor to identify those samples that are not suitable to be tested in the geotechnical laboratory or that require further health and safety assessment over and above the standard risk assessment.

Designers should also take into account the extent to which laboratory tests can impact on the health of those conducting the testing and should look for alternatives where significant hazards are foreseeable.

## 17.9 Contaminated ground

The possibility of contaminated ground being present should be taken into account for all ground investigations to ensure the safety and protection of site staff, the public and the environment including water courses and groundwater. Investigations for contamination should be carried out in accordance with BS 10175.

*NOTE 1 Guidance on safe working on contaminated sites can be found in BS 10381-3 and CIRIA R132 [1]. Where asbestos might occur, more specific advice is given in the AGS guidance [4].*

Ground investigations for geotechnical purposes should only be undertaken following evaluation of whether, in the absence of information on contamination or ground gas, the potential risks to human health and safety or the environment are acceptable.

Geotechnical investigations that have not been designed primarily to investigate contaminated ground might provide an opportunity to obtain information on contamination, either incidentally, or as part of an integrated investigation (see 17.8); however, incidental sampling should never be regarded as a substitute for a proper investigation for contamination.

Samples that might be contaminated should be tested in a laboratory specializing in the type of testing appropriate to the nature of the likely hazard to identify if they are suitable for geotechnical laboratory testing.

*NOTE 2 Contamination, if present, can have implications for undertaking geotechnical laboratory testing. These implications might range from the adoption of appropriate precautions to ensure the safety of the laboratory staff to a decision about whether the particular test scheduled is viable at all (see Clark and Keeton, 1995 [15]).*

A protocol for screening to identify any contamination should be established. While the detailed procedures might vary on a project specific basis, the overriding principle should be that the geotechnical advisor has the responsibility for the information flow.

Any changes to the geotechnical laboratory testing regime should be discussed with the geotechnical advisor.

When establishing the extent of the ground 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 should be taken into account. The type, spacing and depth of investigation points should be determined by the objectives of the investigation, as well as the geological conditions, the nature and extent of the contamination, and the proposed end use.

*NOTE 3 With these types of investigation there are likely to be further special requirements regarding sampling, sample containers, sample transport, sample storage and time elapsed between sampling and testing (see BS 10175).*

*NOTE 4 BS 10175 provides guidance on the investigation of land potentially affected by contamination and land with naturally elevated concentrations of potentially harmful substances, to determine or manage any risks.*

### 17.10 Ground gas

The possibility of ground gas being present should be taken into account and the likelihood of ground gas affecting the ground investigation should be identified as a part of the desk study and field reconnaissance. If the site is likely to be affected by ground gas, an assessment of the hazard should be carried out in accordance with BS 8576.

*NOTE 1 For information on carbon monoxide, see the HSE publication Position statement, carbon monoxide [16]; the CIRIA publication The VOCs handbook [17] for information on volatile organic compounds (VOCs) and Wilson, Card and Haines, 2008 [18] for information on ground gas in general.*

*NOTE 2 Low oxygen content air might occur in deep excavations and during tunnelling operations with or without raised carbon dioxide levels and/or methane concentrations.*

*NOTE 3 For information on radon, see BS 8576:2013, Annex B. The Building Research Establishment has published guidance on the protection of buildings against radon.<sup>9)</sup>*

## 18 Frequency of sampling and testing

### 18.1 General principles

The geotechnical advisor should decide on the frequency of sampling and testing in an exploratory hole, taking account of the following factors:

- a) the guidance given in BS EN 1997-2;
- b) the information that is already available about the ground and groundwater conditions;
- c) the information obtained by any geophysical or other non-intrusive methods forming part of the investigation; and
- d) the technical objectives of the investigation.

*NOTE In the case of a phased investigation (see 17.2), a different sampling and testing programme might be appropriate given that:*

- *the preliminary phase concentrates on the determination of the character and structure of all the strata and the groundwater conditions; and*
- *the design phase concentrates on the determination of the properties of the various strata whose locations have been determined in the preliminary phase.*

Irrespective of phasing, the overall sampling regime should be designed to ensure that:

- the range (numbers and depths) of samples of various quality classes is such as to permit an appropriate suite of tests to be carried out for the anticipated design;
- samples are available for geoenvironmental testing if contamination of the ground proves to be an issue; and
- samples are preserved and handled to maintain their condition as required by the sample type (see 25.11).

<sup>9)</sup> See <<http://www.brebookshop.com>> for recent publications [last viewed 24 June 2015].

## 18.2 Determination of character and structure of the strata

### COMMENTARY ON 18.2

*This subclause only relates to characterizing the ground in relation to stratigraphy and not to obtaining samples for laboratory tests to determine strata properties.*

*In areas where suitable information about the ground conditions has been built up from the results of previous investigations, it might be possible to omit this aspect.*

The location, character and structure of each stratum should be determined, so far as is practicably possible.

*NOTE Some of the strata might be quite thin, and continuous sampling through the full succession might be required in order that the necessary information can be obtained.*

Where highly variable ground conditions are expected, it might be advantageous initially to sink one or more boreholes by rotary core drilling or another continuous sampling method such as resonance/sonic drilling or by percussion boring with consecutive tube sampling. The cores or tube samples should then be examined to give guidance for sampling at selected depths in boreholes subsequently sunk close to the initial boreholes.

In fine soil, and some silty sand, consecutive tube samples may be obtained using a variety of techniques; these samplers, appropriate to different soil types, are given in BS EN ISO 22475-1:2006, Table 3.

In coarse soil, such as gravel, tube sampling is rarely successful and in their absence disturbed samples should be taken from the drill tools (see 25.3), together with any split barrel standard penetration test samples, although in gravels it is likely that the solid cone is used (see 25.4.5).

Sampling procedures should be adopted that allow the recovery of representative samples including the retention of fines.

In some soils and in rock, continuous rotary core sampling (see 25.7) should be undertaken to give the appropriate sample quality; if the core recovery is poor, the use of alternative methods or equipment might be necessary.

A selection of samples obtained by drive sampling or rotary coring should 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.

Groundwater conditions should be determined from the water levels in the exploratory holes, from the identification of water bearing strata and from observations in groundwater monitoring installations set at the appropriate depths (see Clause 26 and Section 8).

## 18.3 The determination of strata properties

After the strata, whose properties are likely to be relevant to the technical objectives of the investigation, have been identified, the properties of those strata should be assessed using appropriate techniques (see BS EN ISO 22475-1). These techniques should include a combination of field observations, field testing, monitoring and laboratory testing (see Section 7 to Section 9).

The programme and frequency of sampling and testing in soil and rock should be designed for the requirements of a particular investigation (for example, geotechnical category of the structure, anticipated ground conditions and depth requirements of the structure) in accordance with BS EN 1997-2.

The sampling and testing scheme should be tailored specifically to the requirements of each ground investigation, taking into account the requirements given in BS EN 1997-2:2007, 3.4.3.

*NOTE* The UK specification for ground investigation [8] gives a default sampling regime related to material types, which might be useful in the early stages of an investigation.

## 18.4 Planning for laboratory testing

### COMMENTARY ON 18.4

*Laboratory tests are used to measure parameters and to complement field observations, field testing and back analysis of the behaviour of existing structures that have been monitored. In some cases, a field test might provide more realistic results because of the differences in scale of the tests, the in-situ test generally testing larger amounts of material without the effects of sample disturbance. However, there is a large body of practical experience behind most of the more common tests and when the data derived from them are integrated and used with skill and experience, reliable predictions usually result.*

The geotechnical advisor should design the laboratory test programme, taking into account the geological and lithological variation, the expected behaviour and the data and parameters required for the geotechnical design. Samples for laboratory testing should be of the quality and size required by the proposed tests.

The programme of laboratory testing and the specification of each test should be determined by the geotechnical advisor, taking account of the requirements of BS EN 1997-2 and the NA to BS EN 1997-2 and other documents as required. The details and number of the tests required to determine the parameters needed for design should be assessed and specified. Each test, or series of tests, should address one or more of the purposes listed below. The principal factors that should be taken into account include:

- a) the nature of the ground and the type of soil or rock being tested;
- b) the quality of the sample and whether it is representative of the characteristics of the ground in situ;
- c) the method of analysis proposed as required in BS EN 1997-1; this might be, for example, an empirical method, a limit equilibrium calculation or a finite element analysis; and
- d) the requirements of the structure and the temporary works, including whether the designs are controlled by stability or by the need to limit deformations, and whether short-term or long-term conditions are most critical.

Discontinuities and weak regions are usually the critical elements in the mass and their shear strength and deformability can be investigated in the field or by large-scale laboratory tests on block samples. The influence of changes in water content on the strength and deformation should be investigated as part of the laboratory test programme.

Planning of the ground investigation and the use of laboratory test results should take into account that recovery of representative samples of some materials can be difficult, for example:

- 1) extremely weak to very weak rock might be poorly represented in borehole core or might be difficult to prepare and test in the laboratory; in these circumstances only the stronger sections of rock core are tested and the results of the laboratory tests are biased;
- 2) materials that contain weaker and stronger components, such as flint within chalk, and gravel and cobbles within clay might be disturbed during sampling.

Strata that could introduce these types of problems should be identified during the desk study. The likely effects on the samples and laboratory test results should be taken into account during the planning of the sampling and laboratory test programme.

## 19 General considerations in the selection of methods of ground investigation

### 19.1 General

The selection of the appropriate equipment for the investigation of ground, groundwater and ground gas conditions (see BS 8576) should take into account the phase of investigation and likely design requirements for the geotechnical category of structure or structures that are proposed.

*NOTE 1 BS EN 1997 places greater emphasis on the need to undertake serviceability limit state design. This requirement might require greater consideration of the stress-strain behaviour of the ground with ground investigations including more in-situ and advanced laboratory testing.*

The geotechnical parameters that are required for design should inform decisions relating to the following:

- type of intrusive equipment (e.g. drilling rigs) to be used;
- type of samplers;
- in-situ testing; and
- monitoring installations.

Regardless of whether in-situ testing is undertaken or samples are recovered, the results obtained should be of the highest possible quality in relation to the likely ground conditions that exist at the site. For soil and rock samples, the choice of appropriate sampler should be considered in relation to the required quality class of the sample. This in turn should be dictated by the type(s) of laboratory testing that is to be performed in order to establish the required design parameters.

*NOTE 2 The availability of equipment and personnel or the cost are not reasons to compromise achieving the required design parameters.*

### 19.2 Site constraints

#### 19.2.1 General

When planning the scope for a ground investigation, there are a number of potential constraints (see 19.2.2 to 19.2.7) that should be taken into account by the designer.

*NOTE The constraints can influence the type of ground investigation equipment to be used and methods of sampling to be employed. In addition, some site constraints have health and safety as well as environmental implications for the ground investigation contractor's workforce as well as for the general public. It is important for the designer to be aware of any site constraints as early as possible, so that they can be identified to the ground investigation contractor.*

#### 19.2.2 Terrain constraints

##### COMMENTARY ON 19.2.2

*There are many possible physical constraints that might affect a ground investigation. These could include access restrictions in terms of the ground conditions as well as the width and height available for the equipment.*



The ground surface conditions and obstructions on the site and accesses to the site should be taken into account in the planning of investigations; these factors could include soft or marshy ground, uneven ground, sloping ground, cliffs or breaks in slope, possible flooding, buildings, gateways, trees and mature shrubs. The area around the investigation positions should include adequate space for working, storing tools and stockpiling excavated materials.

Land affected by shallow mining and quarrying activities should be assessed to identify any shafts, crown holes or areas of potential instability. Land affected by natural cavities such as caves or swallow holes should be assessed to identify any areas of instability. The use of ground investigation equipment in these areas should be carefully assessed.

### 19.2.3 Structure constraints

#### COMMENTARY ON 19.2.3

*In urban areas physical constraints that might affect the placement of investigation points include the presence of existing buildings immediately adjacent to the site to be investigated. There might be overhanging structural elements or basements that extend beyond the apparent footprint of the existing buildings.*

The need for access between and around existing structures should be taken into account in relation to width and headroom; this is particularly the case for investigation points that have to be accessed through other structures.

Exploration of the ground should take account of the possible presence of buried basements, cellars, walls, foundations, tunnels, shafts and pipelines. Where present, structural plans should be consulted to identify the extent of such features prior to designing the investigation.

The stability of existing structures (e.g. retaining walls, pipes, shallow tunnels) should be adequately assessed prior to the undertaking of ground investigation, with particular attention paid to the ability of the existing structure to cope with pressures exerted by a drilling rig or other plant.

Special considerations which apply to investigation points sited within existing structures should be taken into account. Confined space working means that there is the potential for the build-up of dangerous gases emitted from the investigation equipment being used; provision should be made to adequately vent all noxious gases and fumes so as to protect the workforce. In some cases, remotely or electrically powered equipment can be used in order to minimize the risks of exhaust gases in the confined space. The noise associated with operating equipment in confined spaces should also be taken into account.

### 19.2.4 Utility constraints

#### COMMENTARY ON 19.2.4

*There is a plethora of buried and overhead utilities both in rural and urban areas. Although the concentration of such utilities is far greater in urban areas, the same procedures are used to identify their location prior to any investigation taking place.*

The locating of utilities should be carried out by desk study, specialist search, on-site search survey, on-site location and inspection holes, as appropriate. The designer of the investigation should identify the location of utilities prior to any investigation taking place; this task may be delegated to the contractor.

*NOTE 1 Certain utilities impose minimum distance criteria for investigation depending on the proposed investigation techniques. For example, there is a minimum distance for the formation of cable percussive and rotary drilled boreholes from buried cast iron water and gas pipes. There is also a restriction on the distance of a rig mast from overhead power lines. General guidance on minimum distances is available from the Health and Safety Executive documents HSG47 [3] and HSE AIS No 8 [19]; individual utility companies might have specific requirements.*

*NOTE 2* Vibration monitoring might be required by utility companies for those exploratory hole positions that could potentially impact adjacent buried pipelines and services.

Once the likely types of utility present on a site have been identified, the ground investigation designer should make due allowance in their siting of investigation points.

Overhead utilities (pylons, telephone wires, etc.) should be taken into account during pre-planning site desk studies and field reconnaissance. During such reconnaissance visits, any evidence of services in the form of accesses or signage (such as manhole covers, inspection pits, hedgeline markers) should be noted and reported as this assists with the identification of buried utilities and thus the siting of investigation points.

Underground utility detection of varying levels of detail should be carried out in accordance with PAS 128.

Utilities within the top two metres of ground are usually searched for using inspection pits, cable avoidance tool (CAT), scanning and ground probing radar (GPR). For deeper structures, such as many sewers and tunnels, such methods are not suitable and they might not be identified or shown on Ordnance Survey maps; therefore reference should be made to utility organizations. Specialist search companies may be used for this as the right contacts should be used to ensure that the search is comprehensive. An appropriately designed geophysical survey should deploy techniques that are able to resolve features at greater depth, and the potential use of these technologies should also be evaluated.

### 19.2.5 Environmental constraints

#### COMMENTARY ON 19.2.5

*On any brownfield site and on many greenfield sites (e.g. agricultural land), there is a possibility that agents or substances potentially harmful to humans, or other potential receptors such as local flora and fauna, the water environment or structures, might be present. Alternatively, or in addition, naturally elevated concentrations of potentially hazardous substances (e.g. arsenic, methane, radon) might be present.*

To ensure the safety and protection of site staff, the public and the environment, the geotechnical adviser should assess and communicate the potential risks arising from contamination or the presence of naturally elevated concentrations of potentially hazardous substances in the ground or groundwater.

A desk study and field reconnaissance should be carried out in accordance with BS 10175 to properly identify the potential for hazardous substances to be present, either naturally or as a result of human activity.

All sites should be categorized by the designer as either green, yellow or red (see BDA guidance [2]).

*NOTE 1* Green sites are those where there is little potential to cause permanent harm to humans; yellow sites are those where the substances are not sufficiently harmful to cause death but nevertheless require protection to be worn; red sites are those where the substances could subject persons to risk of injury, impairment or death.

If a site is categorized as red, the geotechnical adviser should select methods to obtain information on the ground conditions without causing disturbance or movement of existing contamination and should ensure the health and safety of the ground investigation contractor's workforce.

*NOTE 2* The use of rotary drilling techniques in contaminated ground can spread contaminants both laterally and vertically unless careful control of the flushing medium is exercised.

NOTE 3 For further guidance on environmental constraints, see BS 10175.

### 19.2.6 Seasonal and ecological constraints

Seasonal constraints such as fields being ploughed, planted or harvested or animals' breeding seasons should be taken into account.

NOTE 1 There might also be environmental constraints imposed by sites having a protected status, such as Sites of Special Scientific Interest (SSSI).

The potential presence of invasive or noxious species should be taken into account. Care should be taken to avoid:

- a) the spread of invasive or injurious plants (e.g. Japanese knotweed [*Fallopia japonica*], Himalayan balsam [*Impatiens glanulifera*], Giant hogweed [*Heracleum mantegazzium*]);
- b) the spread of infective agents, including for example those causing foot/hoof and mouth disease (*Aphatae epizooticae*) and rhizomania (*Benyvirus* – Beet Necrotic Yellow Vein Virus [BNYVV]);
- c) the spread of genetically modified (GM) crops outside of areas approved for their growth.

Such potential risks should be identified and at an early stage and addressed by site management procedures and appropriate guidance provided to site operatives, including in respect of species such as Giant hogweed that can cause harm to humans. Specialist advice should be sought at the desk study and field reconnaissance stage and at other stages of the investigation as necessary.

NOTE 2 The listing above of invasive, noxious and injurious plants and infective agents is not exhaustive.

NOTE 3 Guidance on the management of Japanese knotweed on development sites has been provided by the Environment Agency in their document The Knotweed Code of Practice [20]. Background information on invasive and injurious species can be found at:

<[www.gov.uk/japanese-knotweed-giant-hogweed-and-other-invasive-plants](http://www.gov.uk/japanese-knotweed-giant-hogweed-and-other-invasive-plants)> [last viewed 24 June 2015].

### 19.2.7 Special constraints

#### COMMENTARY ON 19.2.7

On any site there exists the possibility that there are constraints that lie outside those that would normally be expected. Such special constraints might include but are not limited to, unexploded ordnance (see CIRIA C681 [21]), radioactive waste, unusually difficult access or working environments.

The geotechnical adviser should identify any special constraints and assess whether they preclude the use of certain investigatory techniques. If there is doubt over what techniques can be used on such sites, ground investigation contractors should be consulted in order to confirm what techniques are appropriate and what the associated risks might be.

## 20 The effect of ground conditions on the selection of methods of intrusive investigation

### 20.1 General

#### COMMENTARY ON 20.1

*The various methods of forming exploratory holes described in Clause 25 are not all equally suited to each type of soil, or to rock. Similarly, the sampling techniques described in Clause 26 do not work in all ground irrespective of its nature. In fine soils undisturbed sampling is often practicable thereby allowing determinations of engineering parameters (most commonly strength and stiffness) by laboratory test, although field testing might also be used. In coarse soils undisturbed sampling is extremely difficult so generally field testing is used to obtain the engineering parameters. Field testing is described in Section 7; some types of test are carried out within boreholes, e.g. the standard penetration test, whereas others are investigation points in their own right, e.g. the cone penetration test.*

The character of the ground, as anticipated from the desk study, should be taken into account in the planning of an investigation. The factors involved in the choice of the most suitable procedures for intrusive investigations in the range of soil types and in rock are covered in 20.2 to 20.11 where frequent reference is made to sample quality classes and these are defined in 26.2. The aspects covered in 20.2 to 20.11 are excavations (trial/observation pits and trenches) and boreholes (by the most relevant drilling methods) together with sampling and field testing.

*NOTE For further information, see BS EN 1997-2:2007, Section 3 and BS EN ISO 22475-1:2006, Section 5. An overview of methods of forming exploratory holes and sampling from them, along with other aspects of investigation, is given by Clayton et al., 1995 [22].*

Appropriate sample quality should form the basis of the selection of the methods for intrusive fieldwork for all investigation phases. The quality class of sample needed to conform to testing requirements in the laboratory should dictate the category of sampler to be used and thereby influence the selection of the appropriate method(s) of investigation. Where the nature of the ground precludes the recovery of samples of an adequate quality class, the use of field testing for the assessment of engineering parameters should be evaluated.

When working with interlayered ground (e.g. soil/rock or clay/gravel), the drilling method should be selected with the aim of ensuring recovery of appropriate quality samples of both the stronger and weaker, or finer and coarser, materials.

Groundwater conditions should be determined (see Clause 26) using appropriate methods of exploration.

### 20.2 Boulders and cobbles

#### COMMENTARY ON 20.2

*The presence of boulders and cobbles (particles of dimensions greater than 63 mm), whether as the principal or secondary fractions, presents significant difficulties to drilling and sampling. The largest particles obstruct the drilling process for most type of boreholes, often being the obstacle to any further progress. Where they do not cause early termination, these particles often have to be broken into smaller fragments by the drilling tools to allow them to pass up the hole. This results in samples which are unrepresentative both because they do not contain the largest particles and because the sample recovered is not of sufficient size to be representative of in-situ conditions (see BS 1377-2:1990, Figure 10).*

When planning an intrusive investigation, which is likely to encounter soils containing very coarse particles (and a matrix of finer soil), the following, which relate to the boulder and cobble fraction, should be taken into account and prioritized over the considerations for gravel and sand fractions (see 20.3) and silt and clay fractions (see 20.4 to 20.6).

- a) Dry excavations (see 24.2 and 24.3) are the best method for examining this type of ground, although there are depth limitations. They enable the structure of the ground to be inspected, disturbed samples to be obtained and field tests for the determination of the in-situ density, undrained strength and deformation characteristics to be carried out on the matrix. However, it is not normally economic to extend excavations below the groundwater table where the ground is sufficiently permeable to allow inflows.
- b) Boreholes can often be difficult to advance through the cobbles and more particularly the boulders.
  - 1) Dynamic sampling (see 24.6) is unlikely to get past very coarse particles.
  - 2) Cable percussion boring (see 24.8) using a shell and, where necessary, supporting the sides of the borehole with casing is more suitable than dynamic sampling because a chisel can be used to attempt to break up or push to one side particles that are too large to enter the shell. Where the matrix is fine soil it is often necessary to resort to alternate use of the chisel and claycutter. However, progress is slow and might not be successful in getting past the boulders. 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 matrix is washed out.
  - 3) Resonance drilling (see 24.7) and rotary drilling (see 24.10) are usually faster and less likely to be terminated due to effective refusal.
  - 4) Rotary open hole drilling (see 24.10.2) would be expected to penetrate the very coarse particles. Simultaneous casing systems allow tube samples and standard penetration tests to be attempted as the hole is advanced.
  - 5) Rotary core drilling (see 24.10.3) can be successful when the clay matrix is stiff or very stiff. The core recovery and quality tends to increase with core size. In general, the core size should not be less than about 90 mm diameter (PWF size) and better results might be obtained with cores of 100 mm diameter or larger. Considerable care and expertise is required in the drilling process. The core samples give an indication of the structure of the ground, but the water content and the strength might be altered depending on the drill flush and drilling method.
- c) Samples from boreholes are unlikely to be representative of the full range of particle sizes. The sampling methods described in 25.4 to 25.6 and 25.8 are generally not suitable for this type of ground. However, it might be possible to recover samples of the matrix where this is a fine soil using the 100 mm open-tube sampler, but the sampler frequently cannot be driven past the coarser particles. The quantity and grain size of the coarse and very coarse particles determines what class of sample can be recovered. Clays containing a small proportion of fine and medium gravel might be sampled with thin wall samplers and might yield Class 1 samples. Conventional 100 mm thick-walled open-tube samplers yield Class 2 samples at best. With increasing percentages of the coarse fraction, primarily gravel, the quality of recovered sample is likely to decrease markedly. In resonance drilling, the coarsest particles are likely to be missing from samples taken with the sonic barrel. However, both resonance and rotary drilling might

give an indication of the prevalence and nature of very coarse particles and their dimension along the axis of the borehole.

As it is virtually impossible to recover undisturbed samples, field testing is likely to be required to obtain an indication of density, compressibility and permeability; there are various methods which should be evaluated for use (see Section 7).

Investigation of such soils requires a range of tests to characterize the in-situ condition; these should include a selection of the following:

- i) Within boreholes the standard penetration test gives some indication of the relative density where the matrix is a coarse soil, or undrained shear strength (derived by correlation) where the matrix is a fine soil. However, the test gives unrealistically high results where the tool bears directly on a boulder or cobble. It is common practice to use the 60° cone in place of the cutting shoe because it is less susceptible to damage by the coarser particles.
- ii) The static cone penetration test and dynamic probing can give useful results provided the density/strength of the matrix is not too high. However, both are likely to be terminated due to effective refusal on encountering a boulder or cobble.
- iii) While such ground is not generally suitable for self-boring pressuremeters, test pockets can be formed such that down hole pressuremeter testing might be undertaken.
- iv) Plate load tests might be used as a means of obtaining more accurate strength and stiffness parameters. Such tests can be performed in boreholes but more commonly in shallow excavations. A plate of sufficient diameter in relation to the largest particle size should be used. If boulders occur, the site beneath the test should be excavated to ensure that the results are not affected by very large particles.
- v) The borehole permeability test might 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.

*NOTE The use of alternate tube samples and standard penetration tests is a frequently adopted expedient where the matrix is a fine soil.*

### 20.3 Gravel and sand

#### COMMENTARY ON 20.3

*Gravel and sand (coarse soils) are generally not self-supporting; boreholes usually need to be lined with temporary casings and excavations tend to collapse unless trench sheets or other support systems are used.*

*In boreholes below the water table, some sands tend to "blow" up the hole, loosening the ground below. The tendency to "blow" is usually reduced but might not be completely eliminated by keeping the borehole full of water.*

When planning an intrusive investigation, where gravel and sand is likely to be encountered, the following should be taken into account.

- a) Excavations (see 24.2 and 24.3) can be of limited applicability because vertical faces in coarse soils are inherently unstable. In very favourable conditions such as in sands above the water table it might be possible to obtain from observation pits block samples cut by hand (see 25.10.1) which are quality Class 2 or even Class 1. However, under typical circumstances, trial pits allow the ground to be inspected without personnel entry and Class 4 samples, suitable for particle size distribution, to be obtained from the excavating equipment. Excavations extending below groundwater level

experience water inflow due to the permeable nature of coarse soils; this exacerbates instability and hampers reliable description and sampling of the ground.

- b) Borehole considerations vary to some extent depending on the drilling method.
  - 1) Dynamic sampling (see 24.6) is hindered by borehole wall instability except when using equipment with a simultaneous casing capability, and the addition of water to the borehole to counteract blowing is not readily accommodated.
  - 2) Cable percussion boring (see 24.8) can readily accommodate the use of casings to support the borehole walls. However, the method can militate against the recovery of samples whose grading is representative of the soil in situ. Samples taken with the shell are disturbed and are likely to be Class 5 because they are deficient in fines; the shell arisings should be tipped into a bucket or tank and allowed to settle to mitigate this problem. Below the water table, in addition to keeping the borehole full of water to mitigate against blowing, the shell should be withdrawn slowly and if necessary an undersized shell used.
  - 3) Resonance drilling (see 24.7) provides support to the walls of the borehole as an integral part of the method. However, the addition of water to the borehole to counteract blowing is not readily accommodated.
  - 4) Rotary drilling (see 24.10) is generally only viable with simultaneous casing as would be the case with wireline coring and some proprietary open hole systems.
- c) It is generally not possible to recover undisturbed samples with a tube sampler. The action of forcing a sampler into sand tends to cause a change in volume, even if the area ratio is small (see 25.4.1.3b)), and hence the density of the sample might not be representative of the stratum although the recovered sample might be representative of the particle sizes. In some sands, a piston sampler is effective (see 25.5); this has minimal effect on the density but the water content of the samples might still be unrepresentative of the stratum so it is questionable whether Class 3 can be achieved. In sand and fine gravel samples suitable for particle size distribution, Class 4 samples are usually obtained by using the split-barrel standard penetration test sampler (see 25.4.5). Larger Class 4 samples can sometimes be obtained by using the 100 mm open-tube sampling equipment with a core catcher fitted above the cutting shoe (see 25.4.4). The quality class of samples recovered by dynamic sampling and resonance drilling is discussed in 25.8 and 25.9 respectively. In very favourable circumstances and with a combination of sophisticated equipment and flush it might be possible to recover relatively undisturbed samples, say Class 2, by rotary core drilling (see 25.7).

Given that it is very difficult to obtain representative samples, field testing is likely to be required to obtain an indication of relative density, compressibility and permeability; there are various methods of field testing which should be evaluated for use to obtain an indication of the properties of the ground (see Section 7).

Investigation of such soils requires a range of tests to characterize the in-situ condition; these should include a selection of the following:

- i) Within boreholes the standard penetration test gives some indication of the relative density. However, the results might not be representative of the ground if sand is loosened, as happens when there is blowing below the water table which leads to an underestimate of relative density, or in coarse gravels which can lead to an overestimate.

- ii) The static cone penetration test is an alternative method by which the relative density can be assessed and is not prone to the loosening due to blowing which leads to an underestimate.
- iii) Dynamic probing could give useful results provided the density is not too high. However, the dynamic probe generally only provides quantitative data on the relative density by correlation with the standard penetration test or static cone penetration test and some of the published correlations might not be reliable.
- iv) Approximate values of the strength and compressibility parameters can be estimated empirically from the results of the standard penetration test or, preferably, from the results of the static cone penetration test. Pressuremeter tests might also be used.
- v) Plate tests provide more direct determination of strength and compressibility either in a dry excavation or within a large diameter borehole.
- vi) In-situ permeability may be assessed from borehole permeability tests or by pumping tests.

## 20.4 Silt

### COMMENTARY ON 20.4

*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 coarser grained silts, which approach fine sand in behaviour. Sample tubes can either loosen or densify a silt depending upon grading, water content and tube geometry.*

When planning an intrusive investigation where silt is likely to be encountered, the following should be taken into account.

- a) Excavation face stability is influenced by the grading, the behaviour of finer grained silt is similar to that of clay (see 20.5) whereas that of coarser grained silt is more like a sand (see 20.3)
- b) Borehole considerations are similarly influenced by grading.
- c) Depending on the clay and/or sand content, silt might be sufficiently cohesive to allow the recovery of samples using an open-tube sampler. Because of the relatively low permeability, these samples might permit a reliable determination of water 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 thick walled sampler are usually only Class 3 at best; there can be a tendency to liquefy with dynamic driving of tube samplers. In low or medium strength silt, Class 2 samples can be obtained using a thin-wall sampler, e.g. piston or statistically pushed UT100.

Field testing (see Section 7) might be used in addition laboratory testing on samples and the various methods should be evaluated.

Investigation of such soils requires a range of tests to characterize the in-situ condition; these should include a selection of the following:

- 1) Depending on the clay and/or sand content, which determines material behaviour, the standard penetration test might be used to obtain an indication of the relative density. However, blowing and disturbance caused by the borehole tools can lead to the standard penetration test giving erroneously low results.
- 2) As with sand and gravel (see 20.3), a more reliable indication of relative density or, where the silt behaves as a fine-grained material, undrained shear strength might be obtained using the static cone penetration test.



## 20.5 Soft and firm clay

### COMMENTARY ON 20.5

*Soft and firm clays are amenable to investigation by excavation and by borehole. Undisturbed tube samples can be recovered which allow laboratory testing for strength, compressibility and permeability.*

When planning an intrusive investigation where soft and firm clays are likely to be encountered, the following should be taken into account.

- a) Excavations (see **24.2** and **24.3**) might require support in lower strength clays. Samples obtained from excavating equipment or by hand are likely to be Class 3 or, if water is present, Class 4. Better quality samples might be obtained pushing sample tubes.
- b) Boreholes of most types can be used although considerations vary to some extent depending on the drilling method.
  - 1) Dynamic sampling (see **24.6**) generally has to resort to successive reduction in diameter because the borehole walls squeeze in the lower strength clays.
  - 2) Cable percussion boreholes (see **24.8**) generally need to be cased. Samples obtained from the tools used to advance the borehole are likely to be Class 3 or, if water is present, Class 4.
  - 3) Resonance drilling (**24.7**) is not subject to borehole squeezing as casing is an integral part of the method.
  - 4) Rotary drilling (**24.10**) is viable but less commonly used than cable percussion boring and dynamic sampling. Considerable care should be taken to avoid disturbance by the drilling fluid. Samples obtained by using a thin-walled piston or open-tube sampler (such as the UT100) can be Class 1. Samples taken with a thick wall open-tube (OS-TK/W) sampler (such as the U100) 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 could be Class 2 or 3. The quality classes obtained by dynamic sampling, resonance drilling and rotary core drilling are discussed in **25.8**, **25.9** and **25.7** respectively.
- c) Clays that exhibit permeable fabric, e.g. sand partings or laminae, might require a balancing water head in the borehole as for sands.

*NOTE There might be a significant amount of disturbance in laminated clays due to the drilling process. In addition, samples of laminated clays soften through migration of porewater from the more permeable laminations into the finer laminations. Piston samplers, including samplers up to 250 mm diameter, can be used to obtain in these clays provided the consistency is not too high.*

Field testing (see Section 7) might be used in addition to laboratory testing on samples and the various methods should be evaluated.

Investigation of such soils requires a range of tests to characterize the in-situ condition; these should include a selection of the following:

- i) The static cone penetration test might be used to provide continuous in-situ shear strength profiles.
- ii) The in-situ vane test might be used to measure the undrained shear strength.
- iii) Other types of testing, e.g. pressuremeter and plate tests, might also be used to measure strength and stiffness.

## 20.6 Stiff and very stiff clays

### COMMENTARY ON 20.6

*Stiff and very stiff clays are amenable to investigation by excavation and by borehole in the same way as soft and firm clays. Undisturbed tube samples can be recovered which allow laboratory testing for strength, compressibility and permeability.*

When planning an intrusive investigation where stiff and very stiff clays are likely to be encountered, the following should be taken into account.

- a) Excavations (see **24.2** and **24.3**) are generally expected to stand unsupported in the short term, although this does not obviate the need for precautions if there is to be person entry. Samples obtained from excavating equipment or by hand are likely to be Class 3 or, if water is present, Class 4.
- b) Boreholes of most types are suitable:
  - 1) Dynamic sampling (see **24.6**) and cable percussion method (see **24.8**) require less diameter reduction or casing than in clays of soft and firm consistencies (see **20.5**).
  - 2) Resonance drilling (see **24.7**) can be used.
  - 3) Rotary core drilling (see **24.10.3**) has been used in these clays with considerable success although there is the potential for causing a change of water content.
  - 4) Mechanical augering (see **24.9**) using continuous flight augers, with solid or hollow stems would be viable, although this can lead to difficulties if granular horizons are also encountered.
- c) Samples obtained by using a thin-wall sampler (OS-T/W) can produce class 1 samples in clay of up to very stiff consistency. Ideally the sampler should be pushed statically into the ground, although this might limit the length that can be recovered. Samples of clays in the stiff consistency range taken with a 100 mm thick-walled open-tube sampler (OS-TK/W) usually suffer significant material disturbance and do not produce samples better than Class 2. With very stiff clays there is even greater disturbance and the samples can be no better than Class 3. The quality classes obtained by dynamic sampling and resonance drilling are discussed in **25.8** and **25.9** respectively. Rotary core drilling can produce Class 1 samples although sometimes only a lesser quality is achieved (see **25.7**).

Field testing (see Section 7) might be used in addition laboratory testing on samples and the various methods should be evaluated, particularly where design considerations warrant greater accuracy.

Investigation of such soils requires a range of tests to characterize the in-situ condition; these should include a selection of the following:

- i) Plate tests in large diameter boreholes can be used in the determination of undrained strength and deformation characteristics, although they can give erroneous results below the water table.
- ii) Self-boring pressuremeters or downhole pressuremeters can also be used to obtain in-situ values for shear strength and deformation parameters.
- iii) Standard penetration tests give a useful indication of shear strength but this method does not provide a direct measurement; published correlations can be used to derive shear strength values and other ground parameters.

## 20.7 Peat

### COMMENTARY ON 20.7

*Peat is a material of low strength and very high compressibility. In many investigations establishing the thickness of the peat is all that is required because the engineering solution is to excavate and replace or to found below it.*

When planning an intrusive investigation which is likely to encounter peat, the following should be taken into account.

- a) Excavations (see 24.2 and 24.3) can be problematic, both because vertical faces can be unstable and because where the peat occurs as the surficial layer it might not have sufficient strength to support typical excavating plant
- b) Boreholes are likely to require the use of plant which exerts very low bearing pressures, methods which use lighter weight equipment such as dynamic sampling (see 24.6) are advantageous in this regard.
- c) It is very difficult to recover undisturbed samples; piston samples (see 25.5) and block samples taken with a large samplers (see 25.10.2) are most likely to achieve quality Class 1.

Field testing (see Section 7) might be used and the various methods should be evaluated for inclusion in the intrusive investigation as follows:

- 1) Dynamic probing, either hand-operated or mechanical, might be used to determine the thickness of peat, although these techniques generally do not provide any quantitative information on the shear strength.
- 2) The static cone penetration test might be used to provide continuous in-situ shear strength profiles.

*NOTE Various alternative to the "standard" cone such as the T-bar and piezoball have been developed specifically for cone penetrometer testers (CPT) in peat.*

## 20.8 Anthropogenic ground

The presence and approximate extent of fill on a site from previous human activity such as engineering is normally identifiable from the desk study because it results from some previous engineering works. It is also usually possible to obtain an indication of the nature of the selected materials used; the relevant considerations for the type of material (see 20.2 to 20.7) should be taken into account when planning the investigation.

Made ground is placed with little or no control; the ground investigation should assess the variation in character and quality across the site, which is often random. When planning an intrusive investigation likely to encounter made ground, the following should be taken into account.

- a) Pits and trenches are particularly useful for investigating the nature and variability of made ground (see 25.2).
- b) Conventional methods of boring, sampling and in-situ testing, as appropriate to the character of the ground, should be used to obtain information on the thickness and properties and, to some extent, types of made ground at the particular locations of the boreholes or in-situ test. Boreholes should always be fully cased through uncontrolled made ground to avoid contamination of the natural groundwater and underlying strata.
- c) In combustible fills, temperature measurements should be carried out as a routine part of the investigation.

*NOTE 1 Certain types of made ground do not lend themselves to any type of conventional sampling or in-situ testing. The investigation might have to rely on visual detailed descriptions of the material as the main way of assessing physical properties.*

*NOTE 2 On waste tips, burning materials below ground might give rise to toxic or flammable gas from the borehole. Tip fires can also create voids, which might collapse under the weight of an investigation rig. Lagoons within waste tips might be areas of very soft ground.*

## 20.9 Rock

When planning an intrusive investigation likely to encounter rock, the following should be taken into account.

- a) The use of geophysical profiling methods to determine the depth to rockhead should be evaluated for sites where access or ground conditions are problematic for boreholes, or where the ground conditions are likely to vary on a scale smaller than the practical distance between boreholes.

*NOTE 1 A combination of cable percussion boring (or dynamic sampling) and rotary core drilling with an overlap around the rockhead might be an option but selecting the depth at which to change methods can itself affect the understanding of the rockhead profile.*

- b) Where weaker rock occurs at shallow depth, excavations (pits or trenches) might be used, as block samples can be obtained from these for laboratory testing. Excavations can facilitate in-situ inspection of the soil/rock boundary and of the mass characteristics of the rock, the latter can also be investigated in situ by inspection in shafts or headings (see **24.2**, **24.3** and **24.4**). Boreholes can be progressed in some weaker rocks by the cable percussion method, using the clay cutter, shell or chisel (as appropriate to the character of the rock), or by dynamic sampling methods.
- c) Disturbed samples from the drill tools associated with these exploration techniques are generally Class 5 but might be Class 4 or 5 if recovered by the cable percussive clay cutter.

*NOTE 2 In many extremely weak to weak rocks, samples might be recovered using the driven 100 mm diameter tube sampler. Driving the sampler can cause severe disturbance and the sample might shatter, or break up, making it very difficult, if not impossible, to identify the natural structure of the rock. The samples are often in the quality class range 3 to 5.*

*NOTE 3 Cable percussion boring in rock gives results of limited value, at best it provides a general lithological profile. In many cases, as for example when rock is overlain by boulders, the method generally cannot identify the interface between soil and rock with any certainty.*

*NOTE 4 In weaker rock and in stronger rocks that are closely bedded, jointed, or affected by faulting, there might be difficulty in recovering cores of satisfactory quality and larger-sized equipment producing cores of about 100 mm diameter or greater and the proper selection of barrel and bit type helps to improve the core recovery. The ground investigation contractor can assist in selecting the best combination of equipment.*

- d) Boreholes formed by rotary core drilling should be used where it is necessary to obtain better quality information about the identity and character of the rock. There are many combinations of drilling methods, tools, and core barrel and bit designs in rotary core drilling (see **24.10**); the selection of flushing medium should also be considered carefully. It might be possible to use resonance drilling as an alternative in some circumstances. Rotary core drilling usually produces samples representative of the character and engineering properties of the intact rock material and which might give

some indication of the frequency and dip of discontinuities but not their orientation. Soil-like or weak discontinuity infill might be lost in rotary core samples.

The limited duration of most ground investigations does not usually allow for much experiment to achieve the best results, so the investigation should be designed to employ the most effective method of sampling both weathered and unweathered rock. This should be done in consultation with the ground investigation contractor.

The use of in-situ testing, either within a borehole or an excavation, should also be evaluated when planning the intrusive investigation.

Investigation of rock masses requires a range of tests to characterize the in-situ condition; these should include a selection of the following:

- 1) The standard penetration test (see Clause 39) can be used to give a rough indication of the strength and compressibility of extremely weak and weak rock. This test does not provide direct measurement of these parameters; they are derived from the test results via published correlations.
- 2) The permeability test or the Packer or Lugeon test can be used to give a measure of the mass permeability, which in turn can give an indication of the presence of open joints and discontinuities.
- 3) Plate tests (see Clause 45) and dilatometers such as the pressuremeter (see Clause 41) can be used to investigate deformation properties and possibly also the strength. Both of these tests can provide a number of useful geotechnical parameters for design, that cannot be obtained from other forms of investigation.

In interpreting the in-situ tests, the effects of drilling disturbance of the ground should be taken into account.

## 20.10 Discontinuities

### COMMENTARY ON 20.10

*In most rocks and some soils the behaviour is controlled by the material and mass properties. The mass properties depend largely on the geometry and nature of the discontinuities present. 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. Discontinuities also occur in some soils and can control the mass strength and deformation characteristics.*

*In soils, the discontinuities are often destroyed by the investigation techniques that are used and so the influence of discontinuities is not always considered. It is, however, possible to obtain high-quality large diameter (>100 mm) cores. Such cores can provide good information on such discontinuities and following careful sub sampling can provide samples suitable for laboratory testing that allow the effect of discontinuities on shear strength and compressibility to be measured.*

Where discontinuities are important to the engineering project, this should be taken into account when planning the investigation.

Investigation of discontinuities in rock requires a range of tests to characterize the in-situ condition; these should include a selection of the following:

- a) Rotary core drilling usually gives some indication of the frequency and dip of discontinuities but not their orientation. The use of impression packers, downhole viewers, core orientation devices, formation micro-imaging (FMI) and crosshole geophysical techniques might be useful where greater information on the discontinuity characteristics are required.
- b) Natural or man-made exposures allow data to be obtained on the frequency, orientation and nature of discontinuities. This is best carried out on three orthogonal surfaces.

- c) Block samples from pits can provide class 1 samples. The advantage of these samples is that they can be oriented and the discontinuities in the pit described.

After initial investigations using interpretation of aerial photographs, outcrop logging and the drilling of vertical and inclined oriented holes, further measures should be undertaken if warranted. It might be necessary to undertake mapping of 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.

*NOTE* In some projects, suitable exposures might 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 orientated field 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.

## 21 Ground chemically aggressive or prone to volume change

### 21.1 General

#### COMMENTARY ON 21.1

*Elements of the natural environment can damage man-made materials and structures. Groundwater, soil and rock can contain constituents, mainly sulfates, in amounts sufficient to cause damage to Portland cement concrete, particularly thin members. Soils that contain iron sulfide might oxidize to produce more aggressive ground when disturbed. Some types of natural ground have a corrosive action on metals, particularly on cast iron, owing to electrolytic or other chemical or bacteriological agencies. Damage can also be caused by differential volumetric changes in the ground related to water content variation without chemical change, and heave resulting from oxidation of iron sulfides to form sulfates.*

*In industrial areas, corrosive action might arise from industrial waste products either in situ or that have been dumped on the site or used as fill, or from liquid sources such as leaking tanks, sumps and chemical drains. There might also be bulk materials formed during industrial and mining processes, which are subject to volume change.*

The potential for attack by chemically aggressive ground on any buried concrete, metal or other construction materials should be taken into account when planning an investigation. Similarly, the potential for the ground to damage the proposed structure due to its volume change should be taken into account.

In river and maritime works, the possible corrosive action of fresh water, sea (saline) water and of trade effluents should be taken into account.

*NOTE* In a marine environment, the most severe corrosion is found in the zone that is intermittently wetted or splashed with sea water due to the increase in salinity as the water evaporates. This effect is increased in waters with a high tidal range. In estuarine situations, there might be an adverse condition because of changes in salinity.

## 21.2 Investigation of potential deterioration of concrete

### COMMENTARY ON 21.2

*The principal agents deleterious to concrete are acidic waters and sulfates. Acidic water is commonly found in organic soils (principally peat) or results from oxidation of sulfide-rich soils and rocks; calcium carbonate acts as a buffer to such reactions and thus calcareous soils and rocks of sufficient calcareous content do not tend to form acidic environments, but conditions might remain potentially aggressive in terms of sulfate attack. Calcium sulfate occurs as gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) including crystalline forms (e.g. selenite) in a variety of rocks. Magnesium sulfate also occasionally occurs. Sulfates are also formed by the oxidation of iron pyrites, which occur in grey clays, mudstones and some sands, and many other rocks.*

The aggressivity of the ground to Portland cement concrete should be determined in accordance with *BRE Special Digest 1* [N1]. The laboratory tests carried out should include determination of pH value, sulfide and sulfate content and such other determinands as indicated in *BRE Special Digest 1* [N1] as appropriate in the context of the site under investigation.

## 21.3 Investigation of potential corrosion of metals

The likelihood of corrosive ground conditions should be assessed from geophysical testing, from in-situ measurement of redox potential and electrical conductivity (see BS 1377-9), or from laboratory tests on undisturbed soil specimens and groundwater samples.

When designing a testing programme, the correct conditions should be modelled as disturbance to the ground and the use of imported backfill materials can have a significant impact on the evaluation. Local enquiry should be carried out to ascertain whether corrosion of metals has previously occurred.

## 21.4 Investigation of chemically-induced expansive ground

### COMMENTARY ON 21.4

*Some slags are expansive as they contain calcium oxide and hydroxide and magnesium oxide and hydroxide; steel furnace slags are noted as being expansive, as are some old blast furnace slags. However, modern blast furnace slags are not expansive. A change in the ground conditions, such as an increase in the availability of water or in the water level, could be sufficient to cause expansion of materials that were previously stable.*

The occurrence of bulk materials, which are a by-product of industrial processes, particularly those involving high temperatures, should be treated with caution. Slags should not be used beneath foundations unless their nature is confirmed as stable. Slag expansion testing should be performed if there is doubt.

## 21.5 Industrial causes of aggressive ground

### COMMENTARY ON 21.5

*A wide range of contaminative substances might be present in the ground of a former industrial site, and which 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 number of slags and other burnt materials might contain high sulfate contents.*

A thorough investigation of potentially aggressive chemicals should be carried out as part of any ground investigation on a former industrial site (see 16.8 and 16.9).

## 21.6 Ground prone to volume change due to water content changes

### COMMENTARY ON 21.6

*All clay soils, to some degree, change their volume dependant on their water content. In general terms, the plasticity index can be used as an indicator of the shrink/swell potential of a clay.*

The potential for soil to shrink and swell due to changes in water content and thus cause damage to buildings or other structures should be investigated; changes in water content might be caused by the presence, planting or felling of nearby trees or shrubs, soakaways, drains or sources of heat or cold.

*NOTE* See NHBC standards, Part 4 [23] for guidance.

## 21.7 Ground prone to dissolution

### COMMENTARY ON 21.7

Some rocks are prone to dissolution and voids might occur beneath apparently solid material. Calcareous rocks such as chalk and limestone, gypsiferous and salt-rich rocks are prone to dissolution over time and might form depressions at the surface masked by superficial materials, or voids at depth that migrate towards the surface. In the case of chalk, the existence and thickness of superficial deposits does to some degree influence the risk of cavities. Further guidance is included within Annex F.

Investigations in areas where there is ground prone to dissolution should examine whether the potential for the problem has been realized; this process starts in the desk study and field reconnaissance. The voids or areas of weaker ground might only be picked up by a closely spaced investigation or geophysical techniques.

# 22 Ground investigations over water

## 22.1 General

### COMMENTARY ON 22.1

Ground investigations conducted over water are more expensive and time consuming than comparable investigations conducted on land, and there can be a temptation to reduce the scope of the investigation; economies in this direction can turn out to be false.

The scope and extent of ground investigations over water should be realistically assessed so as to be commensurate with the proposed construction.

*NOTE 1* Further guidance on undertaking ground investigations over water can be found in BS EN ISO 19901-8.

Geophysical surveys should be used at the planning stage where needed to provide geological information for the ground beneath the construction site and the positioning of the investigation boreholes.

Owing to the difficulties in sinking boreholes below water (particularly with regard to rotary core drilling, rotary open hole drilling, cone penetrometer testing (CPT) and certain in-situ testing and sampling techniques), working platforms should be fixed/elevated or floating with heave compensated drilling equipment fitted. A conductor pipe should be suspended from the platform to protect the flexible investigation string from the forces of currents. Percussion boring and rotary drilling techniques, both conventional and wireline, can be employed. Geophysical logging techniques should be employed where needed to augment the information obtained from the borehole programme.



*NOTE 2* Increasing use is being made of a variety of penetration testing and sampling techniques, originally developed for work further offshore, where specially designed boring, drilling or penetration testing equipment is lowered to the seabed to be operated by remote control or by a diver. Penetration depths vary from less than 5 m for some devices, to 20 m or more for others providing the ground conditions allow.

Over water work is always subject to a risk of delay because of unsuitable environmental factors (weather conditions, sea state and currents); the need to find a balance between a higher daily operating cost and an extended programme with long environmental delays should be taken into account at the planning stage. The scope of the work, including the methods of boring, sampling and in-situ testing, should be planned with the particular difficulties of the site being taken into account.

*NOTE 3* For any given weather condition, the amount of delay depends on the type and size of the installation or working platform. In general, the larger the working platform, the smaller the risk of delays due to weather but, on the other hand, the greater the operating costs.

When working over water, health and safety requirements, navigational warnings, and the regulations of governmental departments and other authorities should all be taken into account. All marine craft utilized, whether floating or elevated, should have the correct marine certification, documentation and should ideally be in class.

*NOTE 4* Class certification is not needed for all near shore/inland waters.

## 22.2 Stages and work platforms

### COMMENTARY ON 22.2

*Where stable working platforms are available or can be provided, such as jack-up drilling platforms, jetties or purpose-built scaffold stages and drilling towers, it is normally possible to use conventional dry-land ground investigation boring equipment and conventional methods of sampling and in-situ testing.*

*If borehole locations allow, it might be possible to work from existing structures; if so, it might be necessary to construct a cantilever platform over the water on which to mount the drilling rig.*

*When drilling close to the shore in very shallow water, it might be convenient to construct a scaffold or other tower at the borehole location. In this case, some means of transporting the boring equipment to the work stage is needed as well as all precautions for working over water including a safety support vessel.*

*An environmental loading analysis is also needed prior to mobilizing the work stage to ensure it is robust enough to withstand the local conditions. Some towers are so constructed that they can be moved from one borehole location to another without having to be dismantled.*

*Jack-up platforms 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 stable highly manoeuvrable safe craft from which to operate. Special craft fitted with spud legs can be floated into position but do not elevate out of the water like a jack-up platform. They conform more to floating craft and offer manoeuvrable work platforms but are more environmentally sensitive than jack-up platforms.*

The design of all staging, towers and platforms should be deemed to be "temporary works" and designed accordingly. The design should take into account the capability of the bed to withstand the foundation loads including those associated with the drilling operations. The design should also take into account the effects of the fluctuating water levels and currents due to tides, waves and floating debris.

The choice of jack-up platform or spud leg barge should take into account the bed conditions with regard to leg penetration and in particular rapid leg penetration (punch through). Any jack-up platform used should have a pre-load procedure to ensure that rapid leg penetration is mitigated. Small, near shore, three-legged jack-up platforms should not be used as they do not have a secure pre-load mechanism.

### 22.3 Floating craft

When selecting a floating craft suitable as a boring vessel, the following should be taken into account:

- a) the anchor holding properties of the bed;
- b) the likely weather conditions;
- c) the depth of water;
- d) the strength of currents;
- e) whether the water is sheltered or open; and
- f) whether accommodation is required on board for personnel.

In inland sheltered waters or rivers, a small anchored barge might suffice, but in less sheltered waters a barge should be of substantial size, and anchors should be correspondingly heavy.

*NOTE 1 In offshore conditions, rather than using a floating barge, a jack-up platform could be the chosen work platform; however, in deeper waters a ship can be employed.*

If a barge is used for the work, an auxiliary vessel should be employed to handle the moorings, but in certain cases a ship might be able to lay and pick up its own moorings. Four or six point moorings should be used and anchors should have the best holding capacity feasible for the expected bed conditions. In water depths greater than about 80 m conventional moorings are difficult, and vessels that can be maintained in position by computer-controlled thrusting devices (i.e. dynamically positioned) should be used.

In order to achieve high quality sampling and coring, constant vertical pressure should be maintained between the drill bit and the bottom of the hole.

*NOTE 2 For shallow water investigations, coring is usually carried out using an hydraulic power swivel suspended in the drilling mast or from a fixed feed frame. These methods are only suitable if the drilling machine is mounted on a jack-up or fixed platform, as any significant movement from an unfixed or floating work platform can have a detrimental effect on core quality and risk the loss of broken drill strings.*

*NOTE 3 Dynamically positioned vessels can typically be used in water depths greater 20 m and offer the benefit of not interacting with the seabed apart from at the borehole location meaning that a smaller area of the seabed needs to be assessed to be free of obstructions.*

*NOTE 4 For deeper waters, particularly with swells and where jack-up platforms cannot operate, for high quality coring operations, special techniques of heave compensation such as piggyback coring can be used.*

### 22.4 Inter-tidal working

Sinking boreholes between high and low tide levels should be carried out using scaffold stagings or platforms (see 22.2), 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.

*NOTE Shallow draft jack-up rigs allow for a higher level of operability and safety to all of the above methods as they remain level and stable at all states of the tide.*

## 22.5 Setting-out and locating borehole positions

### COMMENTARY ON 22.5

*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 and provide accurate surveying data.*

*Guidance notes for surveying, including GPS, and for different purposes and equipment are available from the Survey Association's website.<sup>10)</sup> More generic guidance is produced by the Ordnance Survey.<sup>11)</sup>*

The location of investigation points should be established in relation to an appropriate coordinate system. Electronic methods of position fixing should be used wherever possible. Close inshore, boreholes may be set out 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, electronic methods of position fixing should be used; electronic methods are also advantageous in poor visibility conditions.

## 22.6 Determination of reduced level of bed

Reduced levels of the bed should be determined. This should be done:

- a) by determining the elevation of a fixed point on the platform or vessel using DGPS at the same time as measuring the vertical distance to the bed level and the water surface; or
- b) by transferring reduced levels of the water surface to a boring vessel from a tide gauge set up close inshore, which is read at frequent intervals throughout the tidal cycles, to readings of water depth taken at the same time on the boring vessel.

Corrections should be carried out, where necessary, to allow for tidal variations when the readings of the tide gauge and the vessel vary significantly.

*NOTE The depth of water can be difficult to determine where the bed is very soft and reduced levels of strata boundaries would then become less accurate.*

<sup>10)</sup> See <<http://www.tsa-uk.org.uk/for-clients/guidance-notes/>> [last viewed 24 June 2015].

<sup>11)</sup> See <<http://www.ordnancesurvey.co.uk/business-and-government/help-and-support/navigation-technology/gps-beginners-guide.html>> [last viewed 24 June 2015].

## Section 4: Exploratory holes

### 23 Surveying of investigation points

Investigation points should be set out on the ground prior to making the excavations or boreholes.

*NOTE 1 The most common methods of setting out are:*

- a) *using survey equipment including such as GPS (see 22.5) to establish a point on the ground at the coordinates established while planning the investigation; and*
- b) *by sight lines and distances from local features where these are present and on the ground and identifiable on plans of the proposed locations.*

The location and elevations of investigation points should be established in relation to an appropriate coordinate system and datum, such as the National Grid and Ordnance Datum. The accuracy required of the surveying should be specified and/or agreed before the start of the investigation.

*NOTE 2 GPS can achieve surveying to an adequate accuracy, provide coordinates and levels to a global system and thence to a national one.*

*NOTE 3 Local grids are sometimes appropriate, necessitating the use of traditional surveying instruments or conversion from a national system. National Grid references and Ordnance Datum allows the data to be used in future investigations.*

As investigation points are sometimes moved from the initial set out position (for instance, to avoid underground services), the correct "as drilled" locations should be determined and reported, which might require further surveying (see Section 10).

### 24 Excavations and boreholes

#### 24.1 General

Utilities should be identified before any intrusive work commences (see 19.2.4).

#### 24.2 Inspection pits

*COMMENTARY ON 24.2*

Inspection pits are normally used to demonstrate the absence of buried utilities. They are usually small.

Inspection pits should be excavated using suitable hand tools or vacuum excavation techniques. A record should be kept of any utilities that are encountered or a null record made if none are encountered. Inspection pits should be described and sampled in accordance with the recommendations of this British Standard.

*NOTE Such pits can also be used to inspect structural foundations, although these pits are also often referred to as trial pits.*

#### 24.3 Trial pits and trial trenches

*COMMENTARY ON 24.3*

*Trial pits and trial trenches can be used for making a rapid check of the condition of the ground. They permit examination of both horizontal and vertical faces exposed as the pit is dug.*

Trial pits and trenches should not be entered. Trial pits and trenches should be dug using an hydraulic wheeled back-hoe loader or a tracked 360° excavator.

*NOTE 1 The maximum depth of excavation is generally 4 m to 5 m, but might be up to 7 m to 8 m where specialist plant is available.*

The following should be taken into account to ensure the safety of both the excavator and the personnel involved with logging the pit and taking samples:

- a) location of excavator in relation to surrounding structures or above or below ground utilities;
- b) location of excavator in relation to excavation itself;
- c) positioning of spoil heap;
- d) position of geologist/engineering geologist during excavation and when logging; and
- e) exclusion zone for third parties.

If there are any indications of instability in the ground including those due to groundwater, excavation should be stopped, the risks assessed and a method of continued working developed. Pits that are unsupported could collapse soon after being dug, so any logging, sampling and in-situ testing should be carried out as, or immediately after, the pit is excavated.

*NOTE 2 Guidance on safety aspects is provided by the AGS.<sup>12)</sup>*

Working from ground surface, the geologist or engineering geologist should prepare a log of the strata and take disturbed samples from the excavator bucket. 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 *BRE Digest 381* [24]). Whenever possible, the record should include photographs (see Annex H).

*NOTE 3 Further details of reporting are given in Section 10. 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.*

Pits should be backfilled as soon as possible after logging, sampling and testing have been completed, since open pits can be a hazard to the general public (see 24.13).

## 24.4 Observation pits, trenches and shafts

### COMMENTARY ON 24.4

*Observation pits are those where personnel entry is required. By providing access for taking samples and carrying out in-situ tests, observation pits allow 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. Tube samplers can be driven into the floor of the pit and then extracted by the excavator or they can be pushed into the side walls. In-situ testing, such as vane shear strength or in-situ density, can also be carried out.*

*Deep shafts might be constructed by hand or machine excavation using traditional methods for supporting the sides. In suitable ground conditions, shafts approximately 1 m in diameter can be bored using large power-driven augers. In suitable conditions, augered shafts provide a fast and economical expedient for inspection, sampling and testing in situ.*

<sup>12)</sup> See <<http://www.ags.org.uk>> [last viewed 24 June 2015].

*Temporary support of the pit or shaft sides through trench boxes, timber supports and whalings are deemed to be “temporary works” and are used in unstable ground to provide the necessary protection for personnel. 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 or trench sheets can lead to delay and to additional danger as a result of the build-up of water pressure behind them.*

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

As personnel are required to enter observation pits, the sides should be made safe, particularly from sudden collapse. A risk assessment should be carried out prior to commencement of the works to identify the possible modes of collapse and any mitigation measures that can be implemented to make a safe working space.

*NOTE 1 These measures are often carried out to provide support to the pit sides, which can readily be provided by purpose-made metal frames that can be quickly inserted and extracted. Alternatively, it might be possible to excavate the sides to a safe profile by means of a series of benches (see BRE Digest 381 [24]).*

*NOTE 2 Observation pits can vary from shallow unsupported pits to deep supported pits formed to enable detailed logging of the strata, structural inspections, in-situ testing or sampling. Both shallow and deep pits can be formed using either hand excavation, machine excavation or a combination of the two.*

Unsupported large area pits up to about 1 m depth may be entered, provided that the risk assessment has concluded that the soil or rock being excavated is likely to remain stable. Alternatively, pit sides may be benched or battered back to produce a stable face. Such benches or battered sides should be risk assessed by a competent person prior to person entry. However, no depth is completely “safe” and every pit should be assessed in its own right with regard to likely stability, even within the depth range ground level to 1 m.

Working in any excavation is dangerous and the appropriate safety precautions should be followed (see the guidance 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 should be established. Oxygen-consuming engines that emit toxic exhaust fumes, such as petrol-driven pump motors, should not be employed in pits or shafts.

Pits should be backfilled as soon as possible after logging, sampling and testing have been completed, since open pits can be a hazard to the general public (see 24.13). There might be advantages in leaving pits open (at least overnight and possibly longer), as this can allow the excavated surface to partially dry, exposing fissures and fabric better than immediately after excavation; however, any pits to be left open and unattended should be securely fenced off and have hazard signage attached.

## 24.5 Headings (adits)

### COMMENTARY ON 24.5

*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 should be supported.

*NOTE* Driving a heading below the water table presents a major construction difficulty 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 clay.

## 24.6 Hand auger boring

### COMMENTARY ON 24.6

*The hand auger boring method uses light hand-operated equipment and generally no borehole casing is used. The auger and drill rods are usually lifted out of the borehole without the aid of a tripod. Boreholes up to 200 mm diameter to a depth of about 5 m can be made in suitable ground conditions (self-supporting strata without hard obstructions or gravel-size particles).*

The boring should be advanced using a hand-operated auger. Hand auger boreholes may be used to obtain disturbed samples, small open-tube samples and for groundwater observations. Disturbed samples obtained from such borings are likely to be classified as Class 4 at best due to the mixing of soil that takes place as the tools are advanced.

*NOTE* Hand augers can also be used to provide access for in-situ tests, such as the field vane.

## 24.7 Dynamic sampling

### COMMENTARY ON 24.7

*Dynamic sampling is divided into two generic types, commonly referred to as window sampling and windowless sampling, depending on the downhole equipment used. For both types, the sampling tool essentially comprises a hollow steel tube, fitted with a screw-on cutting shoe, to which extension rods can be coupled as necessary as the sampling hole gets deeper. The differences in the sampling tubes are:*

- *Window samplers have longitudinal slots or “windows” cut in the wall on one side of the tube. The soil recovered in the sampler can be examined in the steel tube via the window and disturbed samples can be taken through it. This is the sort of equipment thought to be envisaged by the term “window sampling” in BS EN 1997-2.*
- *Windowless sampling tubes do not have slots, a plastic liner being inserted into the steel tube. The soil recovered can be retained as a sample in the plastic liner or as disturbed samples taken from it. Sample catchers can be included between the cutting shoe and sample liner to retain soil.*

*The method has become popular for shallow geotechnical and, especially, geoenvironmental sampling owing to the recovery of a reasonably complete soil profile, a general absence of spoil, the relatively small size and light weight of the equipment which makes for easier access on restricted sites, smaller transport requirements and lower cost. It works most efficiently if the hole stays open unsupported with only limited squeezing; hence it is best suited to dry cohesive soils. Systems are available for samplers, whereby casings are driven simultaneously with the sampler. Dynamic sampling tubes are generally between 45 mm and 100 mm diameter and in favourable circumstances it is possible to take a sequence of samples down to a maximum depth of about 10 m.*

The sampler should be driven into the ground by percussion using a hand- or rig-operated hammer. The depth interval of drive should not exceed the length of the hollow sampler tube and the equipment is then extracted either manually with a jack, or using the rig hydraulics. The process continues by inserting the sampler, or one of reduced diameter, down the open hole left by the first extraction and driving again. By repeating this process with successive reductions in sampler diameter a useful depth of investigation can frequently be achieved. (The quality classes of the samples is discussed in 25.8.)

*NOTE 1 There are three generic types of dynamic sampling rigs:*

- *Hand held “rigs” comprise electric, hydraulic, pneumatic and petrol percussive hammers commonly used in the construction industry. Sampling depth achievable is limited due to the power and weight of the equipment, which is more suited to window than windowless sampling.*
- *Feed frame mounted, drop weight type rigs mounted typically on a rubber-tracked chassis, a small trailer or as a stand-alone wheeled unit. The larger units of this type can also be capable of carrying out greater diameter tube sampling operations and be able to mount a small rotary head for coring operations. This type of rig is also used to perform dynamic probing (see 38.1).*
- *Feed frame mounted, percussive hammer type rigs. These machines have a percussive hammer attached to a sliding carriage, which, in turn, is mounted on to a feed frame. Typically the sliding carriage is connected to the base machine’s integral feed system and allows thrust to be added to the downward force of the hammer thus increasing penetration rates. Many of these percussive hammer types are combination rigs where the base machine is a rotary rig carrying a rotary head and percussive hammer both mounted on a sideways moveable plate attached to the sliding carriage.*

*NOTE 2 An earlier type of dynamic sample, the “flow through sampler”, has largely become obsolete.*

## 24.8 Resonance drilling

### COMMENTARY ON 24.8

*Resonance drilling, also known as sonic drilling, employs adjustable high frequency sinusoidal vibrations of generally between 50 Hz and 150 Hz to advance drilling tools in soil and rock. The drill head contains an oscillator, which generates resonant energy that is transferred down the drill string to the drill bit. In soil the vibratory action causes the soil particles to fluidize and/or displace at the bit face and immediate surrounds thus reducing friction. The extent of the fluidized zone internally and externally around the bit depends on the ground conditions and can be significant. With application of feed force there is very fast penetration. Casing the hole as it advances is an integral part of the method.*

*Simultaneous rotation of the drill string is possible on some rigs which assists penetration enabling larger diameter holes to greater depths. The hole is usually advanced without flushing although small amounts of water can be added to assist penetration and cuttings removal in difficult soil conditions and rock. Borehole diameters generally range from 80 mm to 200 mm and depths in excess of 100 m can be achieved by the larger rotary-vibratory rigs.*

The procedure should be as follows: to sonically advance the sampling barrel (with simultaneous rotation if appropriate where the capability is available) and then sonically override this with a larger diameter casing before returning the barrel to the surface for sample extraction. This process is repeated until the required depth of hole has been reached.

The sonic barrel can be lined with a rigid plastic liner in which the recovered material is retained after being brought to the surface. Alternatively, if the sonic barrel is unlined, the recovered material should be “extruded” by resonance into a flexible polythene “sausage” bag for examination and subsequent taking of disturbed samples. Recovery of approaching 100% of the soil or rock profile can be achieved in favourable circumstances. However, in some instances, resonance can induce high temperatures in the ground leading to a change in water content in the soil sample and loss of volatile organic compounds. The quality classes of the samples is discussed in 25.9.



*NOTE* Some proprietary systems allow for the use of conventional tube samplers or standard penetration tests between sonic runs or for rotary core drilling with the sonic element turned off. The “downtime” (time spent tripping out one set of equipment for another) associated with using a sonic rig combined with conventional rig sampling needs to be borne in mind when selecting this type of exploratory hole making equipment. The equipment can also be configured to drill open holes for example to facilitate the installation of instrumentation.

## 24.9 Cable percussion boring

### COMMENTARY ON 24.9

*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 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 bailer for granular soils and the chisel for breaking up rock and other hard layers. 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.*

The clay cutter should be used in cohesive soil in a damp or dry borehole. Where the borehole contains water, it might be necessary to use a combination of the clay cutter and the shell in cohesive soil. The shell should be used in granular soils and there should 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 granular strata that require the use of the shell. When the boring advances below the water table granular strata, water should be added to the borehole to sufficient maintain water in the hole at a level above that of the surrounding groundwater. This reduces, but might not eliminate, the tendency for loosening the ground below the base of the hole by ‘blowing’. The shell should be withdrawn slowly and, if necessary, an undersized shell should be used.

Cable percussion boring may be used for soil and weaker rocks. The clay cutter and shell bring up disturbed material which is usually sufficiently representative to permit identification of the strata.

*NOTE 1* The method can conflict with the geotechnical objects of the investigation, which might 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 might be necessary to adopt a less efficient method of boring with the cable percussion rig, e.g. boring a stiff clay under water might need the use of the chisel and shell, or to adopt a different method of drilling such as mechanical augering.

*NOTE 2* Cable percussion drilling can result in significant disturbance and mixing of soil samples. Often, it is not possible to clearly attribute returned soils to a specific geological horizon within the borehole.

Where there is a material need to identify, characterize and delineate contamination, the use of this method should be evaluated to ensure any samples collected meet the data quality objectives required to perform robust subsequent assessment of land contamination risks.

## 24.10 Mechanical augers

### COMMENTARY ON 24.10

*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 can 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 might 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 in suitable materials.*

Continuous-flight augering needs considerable mechanical power and weight so the machine should be 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 might be obtained from driven samples taken through the hollow stem of the auger.

In self-supporting strata, solid rods and a suitable auger tool may 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.

## 24.11 Rotary drilling

### 24.11.1 General

#### COMMENTARY ON 24.11.1

*Rotary drilling methods, in which the drill bit is rotated on the bottom of the borehole, are used to drill rocks and 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. Common drilling fluids include clean water, air or a mixture of both. Mud, polymers or foam are also frequently used to maintain or assist borehole stability, aid the transport of drill cuttings to the surface and maximize core recovery, particularly in soils and weaker rock formations.*

*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 can 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). When recirculating, the drill fluid should be cleaned as an integral part of the process so that it is suitable for continuing reuse.

*NOTE* Drilling is in part an art, and its success is dependent upon good practice and the skill of the lead driller, particularly when coring fractured and extremely to very weak rocks or soils.

### 24.11.2 Open hole drilling

#### COMMENTARY ON 24.11.2

*Open hole drilling is sometimes used in soils and weaker rocks as a rapid and economical means of making holes in the ground for the purpose of advancing the hole to a sampling depth, progressing a hole to a specified depth or material type, for carrying out in-situ tests, for installing instruments, etc. The technique can also be used to probe for voids such as mine workings, solution cavities, etc. Systems are available whereby casings are driven simultaneously with the open hole bit. While drilling, only drill cuttings are returned in the drill fluid.*

The rate of progress of drilling and observations of the flushing medium and the cuttings should be recorded. These records may be made by the lead driller or a separate logger. The cuttings constitute very low quality samples and it is usually difficult to detect a change in strata, unless there is a good contrast in properties such as colour, mineral content or hardness. Where such contrast prevails, open hole drilling can be used as a probing technique.

*NOTE* The use of suitable instrumentation, termed "drilling parameter recording" (DPR) or "measurements while drilling" (MWD), in order to record the progress of the drilling rig can considerably enhance the results obtained (see BS EN ISO 22476-15).

### 24.11.3 Core drilling

#### COMMENTARY ON 24.11.3

*Core drilling is normally carried out using conventional or wireline double or triple tube core barrels fitted with diamond or tungsten tipped core bits. With conventional drilling, the core barrel is run on a string of rods which are rotated by the rig at the surface. This method might require a separate string of casing to support the walls of the borehole. Wireline core barrels are rotated from the surface by drill rods which are normally of the same diameter as the outer core barrel obviating the need for a borehole casing. Information about all the major components found in core barrels, rods and casings is given in BS EN ISO 22475-1.*

*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.*

*With triple tube core barrels, the non-rotating inner barrel contains a removable liner. The liners are usually steel tubes (split or seamless) or plastic (rigid or semi-rigid). They do not increase core recovery or sample quality, but are 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 it is common practice to use conventional double tube barrels with a semi-rigid plastic liner inserted inside the inner barrel; in which case the core diameters in BS EN ISO 22475-1:2006, Annex C reduce because different core bits are required to accommodate the liner.*

*The wireline system differs from the conventional in as much as the core is brought to the surface within the inner core barrel on a wire rope or line attached to an "overshot" recovery tool. Larger diameter wireline systems are particularly suitable where soils and weaker rocks 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 these circumstances in unstable holes not supported by drilling mud or in gravels, collapse of the hole might occur and re-drilling of the collapsed material is then necessary.*

*Detailed information of core barrel sizes and the core sizes they produce is listed in BS EN ISO 22475-1:2006, Annex C.*

The drilling rig and compatible in-hole and surface equipment together with the flushing medium should be selected to meet the objective of achieving optimum core recovery and core quality consistent with cost. General guidance on the available techniques and their suitability to various ground conditions is given in BS EN ISO 22475-1; however, for detailed guidance on the suitability of various techniques in different types of soil and rock, advice should be sought from a drilling specialist. Similarly detailed guidance on the selection of core bits for particular formations and on inter-related matter of the selection suitable the flushing medium for the anticipated geology to be drilled should be sought from a drilling specialist.

*NOTE 1 A very wide range of coring bits is available and the type which gives the best results in any given ground conditions might have to be determined by trial. The factors affecting bit selection for optimum rate of drilling might 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 might occur as the fluid passes between the inside of the bit and the core, although this can 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.*

*NOTE 2 Water and air are the simplest and most commonly used flushing media. Drilling muds consisting of water with clay (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 can be removed at a lower flushing velocity, thereby reducing disturbance and washing out at the cutting bit or within the borehole in weaker rocks or soils. Using air as the flushing medium might 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. Air or water flush can also cause mobilization and mixing of contaminants with related health and safety implications. Whereas water and polymer can tend to increase the natural water content of the core, the use of air tends to reduce it. Air can fracture weaker rocks and create paths of weakness, possibly causing leakage of the air flush and a permanent change to groundwater paths. The use of air flush is undesirable in situations where ground gases are likely to be present because these gases might be displaced outwards along existing pathways or new pathways created.*

Where core samples are needed for laboratory testing, they should be preserved as quickly as possible in order to maintain sample quality, e.g. water content. (Core extrusion and preservation together with the taking of sub-samples for testing is discussed in 25.7.)

## 24.12 Wash boring and other methods

### 24.12.1 Wash boring

#### COMMENTARY ON 24.12.1

*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. Borehole sizes are typically between 65 mm and 150 mm. In collapsing ground, casing is driven down to support the sides of the borehole, or drilling mud can 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 25.4.5 and Clause 39). Open-tube samples or piston samples can be taken in fine soils.*

Wash boring is best suited to sands, silts and clays and should be carried out using appropriate size tools and casings. Its use in gravels is impractical and should be avoided.

*NOTE Wash boring is widely used in North America, but not often in the UK. The technique tends to be used for rock head profiling in near-shore or other aquatic environments where there exists a ready source of water for flush and the nature of superficial deposits is of no concern.*

### 24.12.2 Other methods of drilling

#### COMMENTARY ON 24.12.2

*There are many methods of drilling, 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 ground investigations, limited information about ground conditions can be obtained, provided that the boreholes are drilled under controlled conditions.*

When rotary percussive drilling is used for ground investigation, the rate of penetration should be measured and drilling characteristics should be observed; in addition samples can be taken of the drilling flushings (see Horner and Sherrell, 1977 [25]). The use of suitable instrumentation (DPR or MWD), in order to record the progress of the drilling rig can considerably enhance the results obtained (see 24.11.2).

*NOTE Rotary percussive drilling is commonly used for locating disused mineshafts or other cavities (e.g. mines, workings or dissolution cavities).*

## 24.13 Backfilling excavations and boreholes

Backfilling should be carried out in such a way as to ensure that there is no, or very limited, settlement of the ground and that the backfilled hole does not form a pathway for groundwater or ground gas.

*NOTE 1 Guidance on backfilling in aquifers is provided in the Environment Agency document Decommissioning Redundant Boreholes and Wells [26].*

*NOTE 2 Water flow through inadequately backfilled boreholes or excavations can cause very serious inconvenience if these investigatory holes are on the site of future deep excavations, tunnels or water-retaining structures. It could also lead to the migration of contamination and in turn the future pollution of an aquifer.*

*NOTE 3 Backfilling with arisings is often unsuccessful in preventing the flow of water.*

For boreholes, the backfill material should be of lower permeability than the surrounding ground (see BS EN ISO 22475-1:2006, 5.5). The borehole should be refilled with a cement-based grout introduced at the lowest point by means of a tremie pipe. A cement and bentonite grout, mixed with no more water than is necessary to permit the grout to flow or to be pumped, should be used. The addition of an expanding agent might be necessary. Cement alone, other than Shallow Oil Well cement, should not be used to seal a borehole as it shrinks slightly.

*NOTE 4 The need and specification for the grout is project dependent.*

Pits and trenches are often backfilled with arisings and in these circumstances, the backfill of these excavations should be compacted by means of the excavator bucket or other mechanical means. In special cases, weak concrete or a specified coarse-grained fill might be required. On sites which are categorized as BDA yellow or red, trial pits should be backfilled with care, taking account of any contamination present (see BS 10175 and BS ISO 18400-102 [in preparation]). Appropriate arrangements should be made for the removal and suitable reuse or disposal of any excess arisings.

## 25 Sampling the ground

### 25.1 General

The selection of sampling technique should take into account the quality of the sample required (see 25.2, in particular the method for classifying the quality of the sample given in Table 3). It should also take into account the character of the ground, particularly the extent to which it is disturbed by the sampling process.

In choosing a sampling method, it should be clearly understood whether it is the mass properties or the intact material properties of the ground that are to be determined.

*NOTE 1 The behaviour of the ground mass is often dictated by the presence of weaknesses and discontinuities (see 20.10). It is, therefore, possible to obtain a good sample of material that is unrepresentative of the mass.*

In accordance with BS EN ISO 22475-1, techniques for obtaining soil samples should be divided into three generic groups:

- a) *Sampling by drilling.* Samples taken from the drill tools or from digging equipment in the course of advancing the borehole or excavation by most of the methods given in Clause 24 are likely to be disturbed, Class 3 to 5 (see 25.3). However, this group also includes rotary core drilling, which is capable of recovering a higher quality sample (see 25.7).
- b) *Sampling by sampler.* Historically termed drive sampling, in which a tube (or a split tube), with or without a piston, having a sharp cutting edge at its lower end is forced into the ground, either by a static thrust or by dynamic impact (see 25.4 to 25.6). These samples would normally be expected to be relatively undisturbed, Class 1 and 2, but in some circumstances Class 3.
- c) *Block sampling.* Traditionally in the UK this term was used for cuboid samples specially cut by hand from a trial pit, shaft or heading (see 25.10 and BS EN ISO 22475-1:2006, 6.5.1). However, it is now also used for taking cylindrical samples from boreholes using a large sampler (see BS EN ISO 22475-1:2006, 6.5.2). Both types of sample would be expected to be relatively undisturbed, Class 1 and 2.

*NOTE 2* Samples obtained by techniques b) and c) and rotary core drilling can be 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. 25.4 to 25.10 describe the various sampling techniques and give an indication of the sample qualities that can be obtained.

*NOTE 3* Intact samples obtained by techniques b) and c) and rotary core drilling are usually taken in a vertical direction, although this last method can be carried out at any inclination which might be required to investigate particular features.

In addition to its quality, the size of sample required for laboratory test should be in accordance with BS EN 1997-2, BS 1377 or other relevant standards.

The presence or absence of water in an exploratory hole during sampling or testing can have significant influence on geotechnical properties observed including water content and shear strength. This factor should be taken into account when considering sample quality and interpreting test results.

When taking samples for chemical testing and in particular on potentially contaminated sites, cross-contamination and chemical or biological reactions should be avoided, as these can affect the result. The following measures should be taken to reduce the risks of cross-contamination:

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

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 5.1).

*NOTE 4* A detailed consideration of investigations on potentially contaminated sites is given in BS 10175.

*NOTE 5* Guidance on the cleaning of drilling and other equipment is provided in CIRIA R132 [1].

## 25.2 Sample quality

The sampling procedure should be selected on the basis of the quality of the sample that is required, which depends on the suitability of the sample for the types of laboratory tests to be carried out (see BS EN 1997-2:2007, Section 3 and BS EN ISO 22475-1). Table 3 shows the basis for assessing quality class together with the category of sampler capable of achieving the class.

*NOTE 1* In general, Classes 1, 2 and 3 are achieved with tube samplers, rotary coring or block samples (see 25.1); these are often known as intact samples. Samples from the drill tools (see 25.3) are Class 3, 4 or 5.

*NOTE 2* Laboratory tests cited in Table 3 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 9.

Table 3 Quality classes of soil samples and sampling categories

| Soil properties/Quality classes                     | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Unchanged soil properties                           |   |   |   |   |   |
| Particle size                                       | * | * | * | * |   |
| Water content                                       | * | * | * |   |   |
| Density, density index, permeability                | * | * |   |   |   |
| Compressibility, shear strength                     | * |   |   |   |   |
| Properties that can be determined                   |   |   |   |   |   |
| Sequence of layers                                  | * | * | * | * | * |
| Boundaries of strata – broad                        | * | * | * | * |   |
| Boundaries of layers – fine                         | * | * |   |   |   |
| Atterberg limits, particle density, organic content | * | * | * | * |   |
| Water content                                       | * | * | * |   |   |
| Density, density index, porosity, permeability      | * | * |   |   |   |
| Compressibility, shear strength                     | * |   |   |   |   |
| Sampling categories                                 | A |   | B |   | C |

NOTE 1 Taken from BS EN 1997-2:2007, Table 3.1.

NOTE 2 The sample class for chemical testing performed as part of routine geotechnical testing has been omitted from this table. Samples of quality Class 4 might be suitable for determination of pH, sulfates, total sulfur, carbonate content, chloride content and redox if there are unlikely to be changes in the parameter results. Those samples that are likely to change, for instance those containing sulfide that might oxidize to sulfate, can be of quality Class 3 or better. The laboratory measurement for the assessment of in-situ resistivity uses samples of quality Class 2 or better.

Where Category A sampling methods are used, it is sometimes only possible to obtain samples with some degree of disturbance, i.e. Class 2 at best rather than Class 1. The results of any strength or compressibility tests carried out on such samples should be treated with caution.

NOTE 3 A further consideration in the selection of procedures for taking Class 1 samples is the size of the sample in relation to the likely soil particle size and by the structure of the ground, which for soil is often referred to as "the fabric" (see Rowe, 1972 [27]).

NOTE 4 The presence of coarse particles is likely to adversely affect the quality of the recovered sample. This is due to the disturbance that can occur during sample taking.



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 might 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. However, for general use, samples 100 mm in diameter should be used because the results of laboratory tests can 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 may be used (see Rowe, 1972 [27]).

*NOTE 5 Specifying the use of appropriate samplers is not a guarantee that, for example, Class 1 samples can be obtained. There are a large number of factors that can produce a non-Class 1 sample despite the best endeavours of the designer and qualified operator.*

The quality of recovered samples should be assessed and recorded at certain key times during the investigation and by the following key personnel, as follows:

- a) on site immediately following the taking of samples by the qualified operator of the plant being used and/or the site supervisory staff by assessing the following:
  - 1) soil particle size in relation to sampler in use;
  - 2) voiding in undisturbed samples;
  - 3) partial core recovery;
  - 4) mixing of strata types;
  - 5) breaking up of cobbles or boulders into smaller particles using sampling tools/chiselling;
  - 6) disturbance by stronger inclusion;
  - 7) condition of sample tube;
  - 8) over drilling of previously cored ground to recover sample or core; and
  - 9) recovery of collapsed or squeezing ground.
- b) at the time of scheduling samples for test by the person responsible for scheduling by assessing:
  - 1) use of inappropriate sampler for material type;
  - 2) excessive blows to drive samplers;
  - 3) partial recovery in samplers; and
  - 4) appropriateness of test for soil sample.
- c) during extrusion or preparation of the sample in laboratory by laboratory technicians by assessing material disturbance as exhibited by:
  - 1) laminations turned down on sample margins;
  - 2) disturbance by stronger or weaker inclusions;
  - 3) softening of sample;
  - 4) open fissures;
  - 5) wax ingress into soil fabric;
  - 6) incomplete waxing or sample preservation;
  - 7) obvious drying of sample; and
  - 8) presence of ice crystals (indicating freezing of sample).

This is not an exhaustive list and the geotechnical advisor should satisfy themselves that appropriate checks are in place for each investigation.

### 25.3 Disturbed samples from boring tools or from excavating equipment

#### COMMENTARY ON 25.3

*The quality of the sample depends on the technique used for sinking the borehole or excavation in combination with the nature (particle size range) of the ground (see 20.2 to 20.8) and on whether the ground is dry or wet. For example, when disturbed samples are taken from below water in a borehole or excavation, there is a danger that the samples obtained might not be truly representative of the deposit. This is particularly the case with cable percussion boring in coarse 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 should be taken during sampling by drilling (using the cable percussion method) or by excavating pits:

- a) Class 3: disturbed samples from dry excavations and from dry boreholes;
- b) Class 4: disturbed samples obtained in fine soil from excavations or from boreholes in conditions where water is present; and
- c) Class 5: disturbed samples in coarse soil from wet excavations or from cable percussion boreholes sunk using a shell and also from any borehole sunk by a method in which the drill debris is flushed out of the borehole, e.g. rotary open hole drilling, wash boring.

*NOTE 1 The quality of samples obtained from the dynamic sampling and resonance drilling tools (rather than cable percussion boring) are considered in 25.8 and 25.9 respectively.*

The mass of sample required for various purposes should be determined by the character of the ground and the tests that are to be undertaken (see Table 4 for a guide to the mass of soil sample required for various purposes). Care should be taken that the sample is representative of only the stratum from which it comes, and has not been mixed with other strata.

*NOTE 2 Field samples are sometimes larger than required by the laboratory. Whilst sub-sampling is usually better done in the laboratory under controlled conditions, guidance on pre-treatment in the field to obtain a representative sample from a larger amount of material, for example material excavated from a trial pit, is provided in BS ISO 18400-201 (in preparation).*

Table 4 Mass of soil sample required for various laboratory tests

| Purpose of sample   | Soil                   | Mass of sample required<br>kg |
|---|------------------------|-------------------------------|
| Soil identification, including Atterberg limits; sieve analysis; water content and chemical tests | Clay, silt, sand       | 1                             |
|   | Fine and medium gravel | 5                             |
|   | Coarse gravel          | 30                            |
|   | Cobbles                | 200                           |
|   | Boulders               | 1 000                         |
| 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                           |

*NOTE* For the other tests, the mass required is after removal of the coarser particles in accordance with the test procedure.

## 25.4 Open-tube samplers

### 25.4.1 Principles of design

#### 25.4.1.1 General

##### COMMENTARY ON 25.4.1.1

*Open-tube samplers consist 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 or “down the hole” sliding hammer. A non-return valve allows 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, which has a single sample tube and detachable cutting shoe. The use of a core catcher is discussed in 25.4.4. Figure 2 shows an open-tube sampler where the cutting edge is machined on to the tube itself.*

All open-tube samplers should conform to the general geometry (diameter, length and the ratio between them) criteria specified in BS EN ISO 22475-1:2006, 6.4.2.2. Open-tube (OS) samplers should be divided into two types in accordance with BS EN ISO 22475-1:2006 – thin-wall (type OS-T/W) and thick-wall (type OS-TK/W). To be deemed a thin-walled type, an open-tube sampler should also conform to the detailed geometry (cutting shoe/sharpened edge) criteria specified in BS EN ISO 22475-1:2006, 6.4.2.3.

*NOTE 1* Ideally, tube samplers cause as little remoulding and disturbance as possible when forced into the ground. However, BS EN ISO 22475-1:2006, Table 2 indicates that quality Class 1 samples from an open-tube sampler are normally only achievable with a thin-walled type.

*NOTE 2* The tube design controls the degree of disturbance. The sampling procedure (see 25.4.2) is also an important factor in controlling sample disturbance.

### 25.4.1.2 General geometry

The open-tube samplers should conform to BS EN ISO 22475-1.

*NOTE 1 BS EN ISO 22475-1 requires a length to diameter ratio of less than 20; commonly used samplers in the UK fulfil this requirement. The most common samplers are about 450 mm long and nominally 100 mm in diameter. Smaller diameter samplers (about 50 mm or 75 mm and generally of the type where the cutting shoe is not detachable) are also used in the UK.*

*NOTE 2 The longest sample tube in general use in the UK is 1 m (for an hydraulic piston sampler, see 25.5). For a 100 mm diameter tube this is still comfortably within the BS EN ISO 22475-1 length to diameter ratio criterion.*

### 25.4.1.3 Detailed geometry

The cutting shoe, if used, should be of a design similar to that shown in Figure 1 and BS EN ISO 22475-1:2006, Figure 4. The cutting shoe (or sharpened edge) should embody the following features (see BS EN ISO 22475-1:2006, 3.3.11, 3.3.12, Figure 1 and 6.4.2.3.2).

- a) *Edge taper angle.* For a thin-walled sampler this should not exceed 5 degrees. However, close to the cutting edge the angle should be increased to 20 degrees or 30 degrees in order to avoid an easily damaged feather edge (see Hvorslev, 1948 [28] and some figures in BS EN ISO 22475-1:2006, Annex C).
- b) *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. For a thin-walled sampler it should be less than 15%.
- c) *Inside clearance.* The internal diameter of the cutting shoe,  $D_1$ , should be slightly less than that of the sample tube,  $D_3$ , to allow for slight elastic expansion of the sample as it enters the tube, reducing frictional drag from the inside wall of the tube and helping to retain the sample. A large inside clearance should be avoided since it would permit the sample to expand, thereby increasing the disturbance. For a thin-walled sampler it should be less than 0.5%.

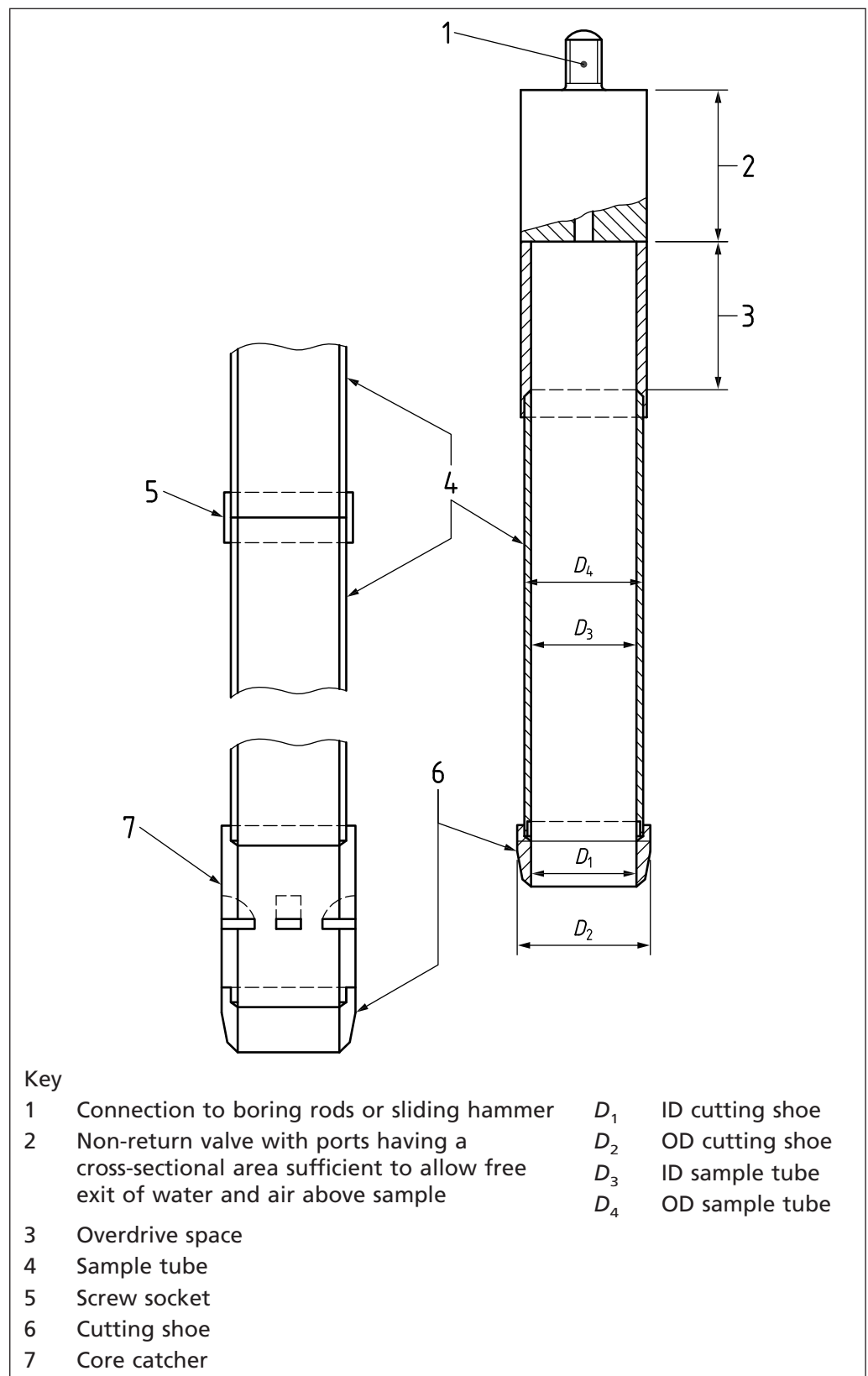
*NOTE In addition to a) and b) above, BS EN ISO 22475-1:2006, 6.4.2.3.2 allows for taper angles of between 5 degrees and 15 degrees and an area ratio of up to 25% but only if it can be demonstrated that the sample quality class is not affected. It also notes that for area ratios exceeding 15% the angle of the cutting edge decreases as the wall thickness increases*

Outside clearance is defined in BS EN ISO 22475-1:2006, 3.3.13 but no quantitative criteria are set. The outside diameter of the cutting shoe should be kept to a minimum, without being less than the outside diameter of the sampler.

### 25.4.1.4 Wall friction

In addition to a suitable inside clearance (see 25.4.1.3), wall friction should be reduced by maintaining a clean, smooth finish to the inside of the tube. A lubricant may be used within the sampler but it should not change the character of or contaminate the sample or the ground.

Figure 1 Basic details of open-tube sampler



### 25.4.1.5 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 a seal to assist in retention of the sample when removing the sampler from the borehole.

### 25.4.2 Sampling procedure

#### COMMENTARY ON 25.4.2

*BS EN ISO 22475-1:2006, 6.4.2.5 gives a procedure for sampling with an open-tube (and a piston) sampler.*

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.

*NOTE 1 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 soils occurring below the bottom of the borehole or excavation might be disturbed if the natural water pressure exceeds the pressure imposed by the water within the borehole or excavation. To reduce this effect, the level of the borehole water should be maintained above the groundwater level appropriate to the location of the sample.

The sampler should be advanced into the ground by a continuous static thrust or by dynamic means (using a drop weight, sliding hammer or percussive head). With a static thrust, the sampler advance should be made in one continuous motion.

*NOTE 2 Static thrust can be achieved by pushing with the rig (where it is equipped with a suitable hydraulic thrust mechanism), or by an independent hydraulic jack or block and tackle.*

If the sampler is dynamically driven, the drop weight should preferably impinge directly on the sampler head and have a mass sufficient to achieve the required penetration by the minimum number of blows. The quality of the sample that can be achieved is affected by these sampling procedures and the maintenance of the sampler in the vertical position.

*NOTE 3 In the UK, cable percussion boring customarily makes use of down the hole hammers, which are manufactured typically with a slide length of less than 700 mm and a mass of either 40 kg or 50 kg. However, the energy imparted is subject to the operator's judgement of actual drop height, whether the mass is supplemented with "sinker bars" coupled to the hammer and whether there is buoyancy effect due to water in the borehole.*

*NOTE 4 In the UK, dynamic sampling rigs generally have either percussive heads or frame mounted drop weights which are used for dynamic driving the sampler via a string of rods.*

The distance that the tube is driven should be checked and recorded because, if driven too far, the soil is compressed and damaged in the sampler; the penetration should not exceed the effective sampler length, particularly where the sampler used does not include an overdrive space (such as in Figure 1). In such cases the drive length should be limited to allow some head space to prevent compressional damage. The thrust or driving effort for each sample may be recorded as a qualitative indication of the consistency of the ground.

*NOTE 5 A sampling head with an overdrive space (see Figure 1) allows the sample tube to be completely filled without increased likelihood of damaging the sample.*

After driving, the sampler should be kept in position for a few minutes and then, if possible, rotated or raised slowly.

*NOTE 6 This allows adhesion to develop between the sample and the sampler tube and then the sample to be sheared off at the bottom edge of the sampler.*

The sampler should be 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.

*NOTE 7 For example, if the length of the sample is less than the distance driven, the sample might have experienced some compression or, alternatively, the sample tool could have permitted some of the sample to slip out as the tool was being withdrawn.*

### 25.4.3 Thin-walled open-tube samplers (Type OS-T/W)

#### COMMENTARY ON 25.4.3

*Thin-walled samplers consist of a steel tube whose lower end is shaped to form a cutting edge. A typical thin-walled sampler is illustrated in Figure 2. An alternative thin-walled sampler incorporates a separate cutting shoe (and an optional core catcher); this sampler, see Gosling and Baldwin, 2010 [29], has been developed from the U100 (see 25.4.4).*

*These samplers are usually only suitable for fine soils up to firm or stiff consistency, and free from coarse particles, although samples have been successfully obtained from very stiff soils. They can 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.*

The detailed geometry of thin-walled samplers should conform to 25.4.1.3. They should be pushed into the soil by continuous static thrust. Alternatively, they may be driven in accordance with 25.4.2 but a lower quality of sample is likely to be recovered.

*NOTE 1 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 25.5).*

*NOTE 2 A variant of the open-tube sampler was developed specifically for recovering samples of sand from below the water table which presents special problems because the sample tends to fall out of the sample tube. A compressed air sampler as described by Bishop, 1948 [30] enables the sample to be removed from the ground into an air chamber and then lifted to the surface without coming into contact with the water in the borehole. The sampler normally takes samples 60 mm in diameter. If the sampler is driven by dynamic means, the change in volume of the sand caused by the driving gives a sample quality no better than Class 3. If static thrust is used, however, Class 2 and sometimes Class 1 samples can usually be recovered. This type of sampler has largely fallen out of use in the UK.*

### 25.4.4 Thick-walled open-tube samplers (Type OS-TK/W)

#### COMMENTARY ON 25.4.4

*A thick-walled open-tube sampler is by definition one that does not comply with the criteria for being thin-walled. In the UK the most common of these is the 100 mm diameter thick-walled open-tube sampler (U100) which has been the tube sampler for routine use with cable percussion boring. 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 thick-walled open-tube sampler can be used in all fine soils and in extremely weak to very weak rock, such as the Southern Province chalk and in the weathered mudstones of the Mercia Mudstone Group. In fine soils of stiff or lower consistency, the standard open-tube sampler (see Figure 1) might give Class 2 samples but, more often, Class 3 samples. In brittle or closely fissured materials, such as certain weaker rocks and very stiff clays, and also in fine grained soils, 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 area ratio of a U100 should not normally exceed 30% and inside clearance is typically about 1%. The use of a liner system, which increases the area ratio up to 50%, should be taken to reduce the sample qualities by one or more classes. The sampler should be driven into the ground, normally using a sliding hammer or drop weight in accordance with 25.4.2.

*NOTE* Soils such as silt and some sands might be recovered with the U100 but are prone to fall out when the sampler 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.

Figure 2 A typical thin-walled sampler

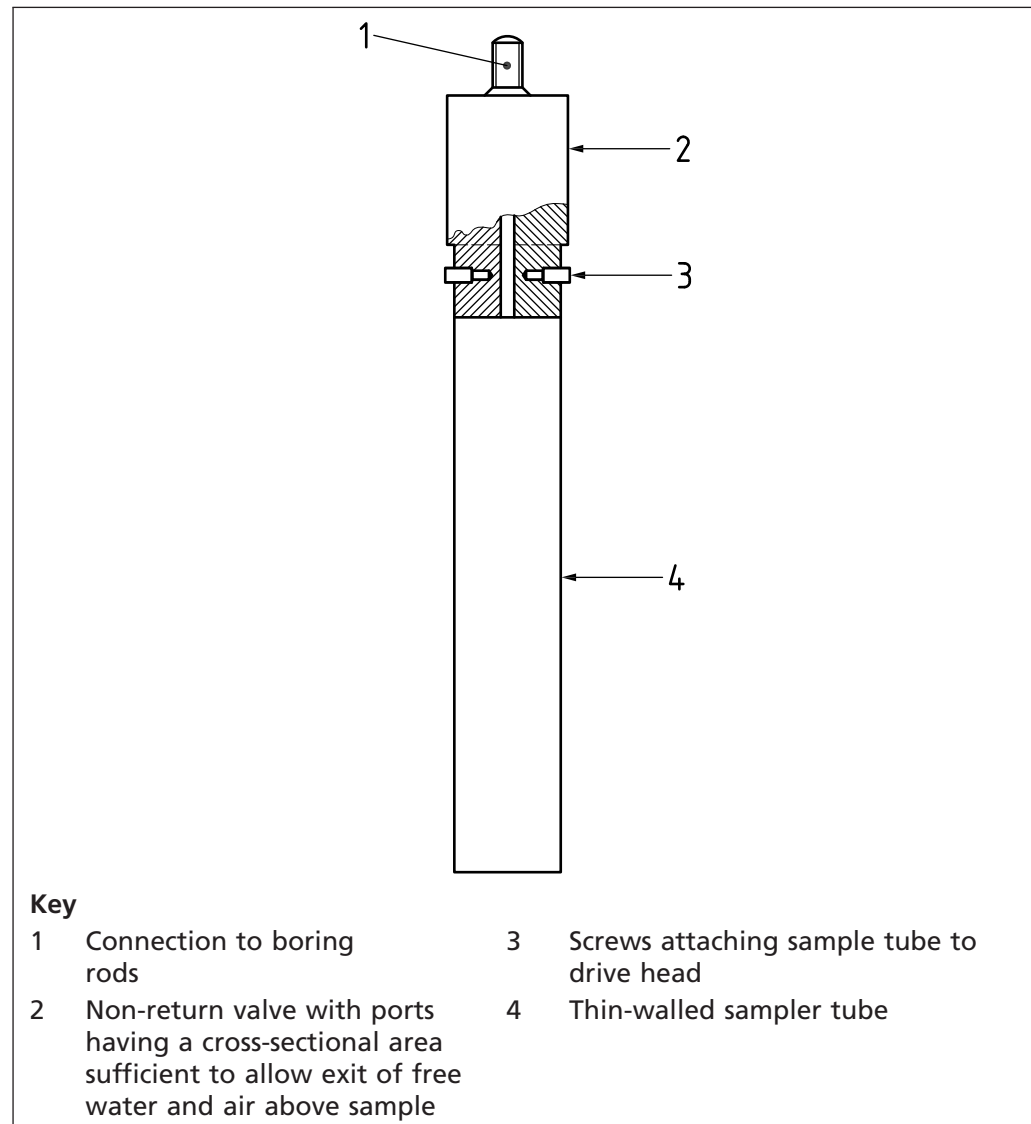
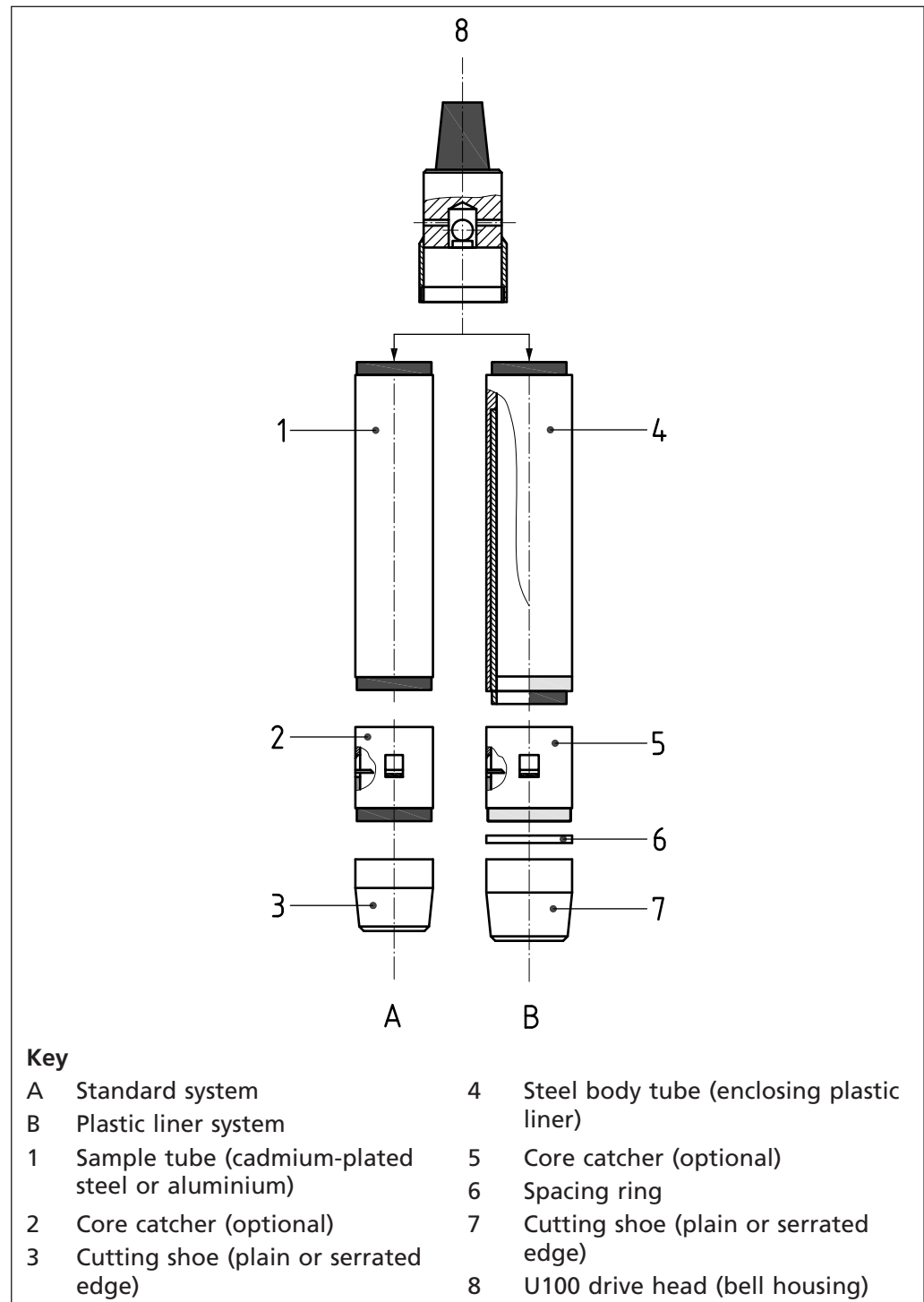




Figure 3 U100 sampler



### 25.4.5 Split-barrel standard penetration test sampler (type S-SPT)

#### COMMENTARY ON 25.4.5

A split-barrel sampler is used in the standard penetration test. 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 100 mm sampler, and gives Class 4 samples.

The equipment and procedure should be in accordance with BS EN ISO 22476-3.

## 25.5 Stationary piston sampler

### 25.5.1 General

The principles of design for open-tube samplers (see 25.4.1) should be applied to the tube of a piston sampler.

*NOTE* As with open-tubes, BS EN ISO 22475-1 identifies thin- and thick-walled types of piston sampler (PS-T/W and PS-TK/W respectively) although the latter are not common in the UK. Figure 4 shows the basic details of a piston sampler.

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

#### COMMENTARY ON 25.5.2

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.

An alternative to the double rod and mechanical locking mechanism is the hydraulically operated piston sampler.

The sampler is normally used in low strength fine soils and can give 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 25.4.3. Although normally used in soft clays, special piston samplers have been designed for use in stiff clays (see Rowe, 1972 [27]).

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 tubes, samples up to 1 m long can be taken.

Initially, the piston should be locked to the lower end of the sample tube to prevent water or slurry from entering the sampler. With the piston in this position, the sampler should be pushed below the bottom of the borehole. When the sample depth is reached, the piston should be held stationary and the sample tube pushed 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.

*NOTE* In clays, and possibly other soils, of firm or lower consistency, piston samples can be taken by progressive penetration from the ground surface (rather than from the base of a borehole); an hydraulic jack might be required to assist the penetration and/or extraction operation.

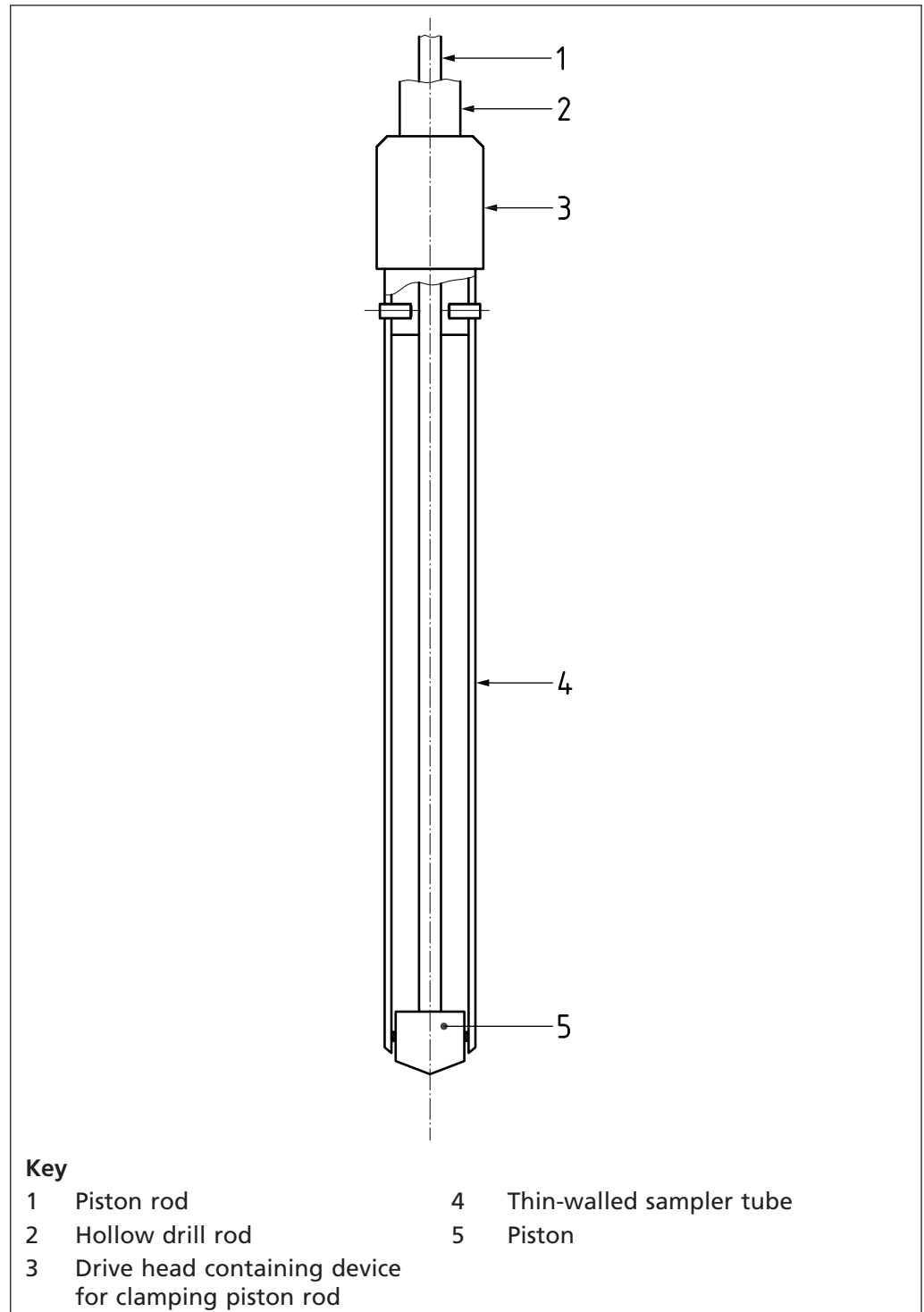
### 25.5.3 Other stationary piston samplers

#### COMMENTARY ON 25.5.3

Variations on the piston sampling method are also available, for example the Mostap sampler as used with cone penetrometer systems takes samples which are typically 1 m long and 35 mm to 65 mm in diameter. The Mostap geometry does not comply with the area ratio criterion for a thin-walled piston sampler. However, the sample is packed in a nylon stocking that is connected to the piston and this stocking reduces the friction between the sample and the sample tube so lessening disturbance.

The Mostap sampler should be pushed into the ground with a cone locked in front of the sample cutting tube. At the desired depth a fishing tool should be 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 should then be pushed further into the soil and so the sample is taken.

Figure 4 Basic details of a piston sampler



## 25.6 Continuous soil sampling

### COMMENTARY ON 25.6

*Continuous soil sampling can produce samples up to 30 m in length in softer soils such as fine alluvial deposits. This is of particular value for identifying the soil fabric (see Rowe, 1972 [27]) and gives results superior to those that can be obtained by consecutive drive sampling. The Swedish system (see Kjellman, Kallstenius and Wager, 1950 [31]) takes samples 68 mm in diameter using steel foils to eliminate inside friction between the sample and the tube wall. The Delft system (see Begeman, 1966 [32]) uses lighter equipment and offers two sizes of sample, 29 mm and 66 mm; this is a thick walled sampler but, akin to the Mostap sampler (see 25.5.3), it uses stockinette (either impregnated or surrounded by fluid and plastic lining tubes) to reduce friction, lessen disturbance and support the sample.*

*Alternative systems for taking semi-continuous samples have been developed to recover consecutive soil samples. An example of this is the Goudsche Machinefabriek (GMF) proprietary system (see French, Woolgar and Saynor, 2000 [33]) where a 66 mm diameter plastic liner is inserted into the sampling tube with cutting shoe. The assembly is hydraulically pushed into the ground for 750 mm under controlled conditions, for example with a cone penetrometer rig. The liner tube with sample can then be recovered using a wireline tool. The sample is labelled and stored. Another liner is then dropped inside the sampling tube and latched into the end section. The procedure is repeated until the required depth is achieved or the limiting capacity of the equipment is reached.*

Continuous and semi-continuous samplers are not readily available in the UK but where the ground conditions are suitable their use should not be discounted. Specialist contractors familiar with the equipment should be engaged to advise on its use and/or operate the sampler.

## 25.7 Rotary core samples

### 25.7.1 General

#### COMMENTARY ON 25.7.1

*Guidance on the various methods of rotary core drilling and information on which soil and rock materials each core sampling type is suited are given in BS EN ISO 22475-1:2006, 6.3.2.1, 6.3.2.2, 7.1, 7.3 and Table 2 and Table 5. The procedures for this sampling by drilling method are described in 24.11. The quality of core samples recovered, and consequently any sub-sample of the core, can vary considerably depending on the character of the ground and the type and size of coring equipment used.*

*Core can be recovered from a variety of material types. The majority of core, however, is likely to be obtained within fine soils of any strength and in rocks in various states of weathering and also having any strength. Some core might be obtained by using double tube core drilling and some by triple tube core drilling; either of these systems can include the use of a semi-rigid plastic liner.*

After the recovery of the core barrel to the surface, handling should be carried out so as to ensure that the recovered core is maintained in a condition as near as possible to its natural state until it is finally stored (see 25.11); it is at this stage that the expense and effort to recover high quality cores can be negated by careless or inappropriate handling.

### 25.7.2 Extrusion

The core barrel should be in a horizontal position when the core is extruded, otherwise it is likely to be disturbed as it is removed from the barrel, and then placed into the core box.

*NOTE 1 This is also preferable even in relatively strong and massive rocks where the barrel might be in a vertical position when the core is removed but this can affect the quality of the core presentation.*

When using a double tube core barrel, the core should be extruded with the tube in a horizontal position 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. The core should be extruded from the core barrel in the same direction as it entered the barrel.

When using a triple tube core barrel, including double tube barrels fitted with a plastic liner, the core should be retained in the liner which is removed from the barrel. Where split steel liners are used, the core may be retained in the bottom half while being logged and then placed in the core box. Where a seamless steel liner is used, the core may be extruded (as per the double tube barrel) before being placed in the core box. Where plastic liners are used, the core should be transferred to the core box still retained in the liner.

*NOTE 2 In weak or fractured rocks and soils, extrusion can lead to core disturbance, however carefully it is done.*

Core should be carefully transferred into core boxes which have receiving channels appropriate to the diameter of the core. Where a plastic liner has been used it should be cut longitudinally with appropriate slitting blades or proprietary coreline cutter tools or vibrating saws, ensuring that the sample is not cut into or disturbed, so that the upper half of the liner can be removed when logging. However, the preparation of core for photography and description should be achieved without compromising the requirements for preservation of sub-samples for laboratory testing.

### 25.7.3 Preservation

#### COMMENTARY ON 25.7.3

*The sampling category cannot be improved once coring has taken place, but inappropriate handling can markedly reduce the quality.*

Soil or rock material recovered as cores should be divided into:

- a) cores not sensitive to water content change: category A status should 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 or film; or
- b) cores sensitive to moisture change: category A status should be maintained by sealing the core immediately with the use of water sealing material, e.g. cheesecloth soaked in wax, waxed sealed tubes. Several layers of the material might be necessary to ensure a complete watertight seal.

*NOTE The use of a soil lathe or similar immediately after recovery to remove the outer layer of the core which has been in contact with the flushing medium is advantageous in maximizing the sample quality.*

Where the core is to be sub-sampled for specific laboratory testing, this should be done immediately after the core has been placed into the core box. When core liner has been used, this should be done by cutting both the liner and core laterally 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 and top and base marked. The sample should be placed in an appropriate container to protect the sample during transport.

All core obtained from the borehole should be preserved for the period of the main works contract to which the core drilling relates; this can be 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. 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 it 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 deemed adjacent to the hinged section. Core retained in the core catcher box should 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 (see Annex H).

## 25.8 Dynamic samplers

### 25.8.1 Window sampling

#### COMMENTARY ON 25.8.1

*The procedures for window sampling are described in 24.7. BS EN ISO 22475-1 includes window sampling in the sampling by using sampler category whereas Baldwin and Gosling, 2009 [34] contend that the method falls into the sampling by drilling category. The distinction might be academic but the quality class of the sample is dependent on the downhole equipment, i.e. the hollow steel tube which both advances the hole and recovers the sample.*

*The sampling tubes are available in lengths of generally 1 m, 2 m or 3 m and a series of some five or six nominal diameters, these being between about 45 mm and 95 mm. The wall thickness of the cutting shoe is typically about 5 mm giving area ratios of about 25% for the largest diameter increasing to about 65% for the smallest.*

The soil recovered in the window sampler tube(s) can only be partly viewed through the "window" itself. In order to properly describe the recovered material, the contents of the tube should be placed into a length of plastic channel. This allows both description to be made and, where required, sampling into small disturbed or bulk disturbed containers. However, a full soil profile can only be recovered under favourable conditions and, in practice, zones of material loss occur. In all cases, the material recovered is fully disturbed and this should be taken into account when considering laboratory testing.

*NOTE BS EN ISO 22475-1 assigns quality class 5 to window sampling; Baldwin and Gosling, 2009 [34] contend that that this is unduly pessimistic and that the quality class is normally 4 or, in favourable circumstances, 3. This is significant in allowing laboratory specimens to be recovered from the samples, provided these are taken immediately after recovery.*

## 25.8.2 Windowless sampling

### COMMENTARY ON 25.8.2

*The procedures for windowless sampling are described in 24.7. Dynamic sampling with the windowless equipment does not appear explicitly in BS EN ISO 22475-1:2006 unless the term “window” in Table 3 of that standard is taken as generic for dynamic sampling. If this is the case, then windowless sampling would be categorized as sampling by use of sampler as suggested by Baldwin and Gosling, 2009 [34]. In effect the sampling hole is advanced by taking a series of consecutive tube samples.*

*It is debateable whether the sampler tubes equate to the tube samplers discussed in 25.4. Windowless sampling tubes are generally 1 m long and are available in a series of five or six nominal diameters, these being between about 45 mm and 100 mm. Due to the plastic liner inserted in the steel sampler tube house, wall thickness of the cutting shoes are about 10 mm, giving area ratios of about 50% for the largest diameter increasing to about 115% for the smallest plastic liner.*

The soil recovered should be retained in the sampler's liner tube(s) until it has been examined and described. At the point of examination, a full soil profile, i.e. approaching 100% recovery, might be available for viewing. Despite the full profile, the material in the tube should be deemed to be relatively disturbed due to the sampler geometry. The samples should be preserved for longer term temporary retention, either in the liners or as bag samples following examination, and a record made of the logger's description.

*NOTE Irrespective of whether the sample is retained in the plastic liner or as disturbed samples in other containers, a quality class normally 4 or in favourable circumstances 3 has been suggested (see Baldwin and Gosling, 2009 [34]).*

## 25.9 Resonance samplers

### COMMENTARY ON 25.9

*With resonance drilling as described in 24.8, samples are recovered with the sonic barrel and retained either in its plastic liner (where fitted) or in a polythene “sausage”.*

The soil or rock recovered should be retained in the sampler's liner tube(s) or polythene “sausage” until it has been examined and described. At the point of examination, a full soil profile, i.e. approaching 100% recovery, might be available for viewing. The samples should be preserved for longer term temporary retention, either in the liners or as bag samples.

*NOTE BS EN ISO 22475-1 indicates that the quality classes are 4 and 5 for cohesive and granular soils respectively irrespective of whether water is present. However, arguably classes 3 and 4 are more realistic, the former being on the proviso that undue heat is not generated by the drilling equipment.*

## 25.10 Block samples

### 25.10.1 Block samples cut by hand

#### COMMENTARY ON 25.10.1

*Block samples cut by hand from materials exposed in excavations are normally taken in fine grained soils (but also in weaker rock) to provide samples for the laboratory determination of strength, deformation and modulus values. The procedure is often used for obtaining specially oriented samples and, in such cases, both the location and the orientation needs to be recorded before the sample is separated from the ground.*

The cutting of a block sample often takes an appreciable time during which there is the potential for the water content to change; the following precautions should be taken.

- a) No extraneous water should be allowed to come into contact with the sample.
- b) The sample should be protected from the wind and the direct sunlight.
- c) Immediately after the sample has been cut, the orientation should be marked and then it should be coated to preserve the water content and density such as muslin and paraffin wax and packed as described in 25.11.6.
- d) Remoulded soil should be carefully removed from the sampling location.

In addition to the measures to preserve water content, the sample should be protected from disturbance during handling and transport to the laboratory, see 25.11.6. This can take the form of a bespoke container.

## 25.10.2 Block samples taken with a large sampler

### COMMENTARY ON 25.10.2

*There are two proprietary types of this generic sampler detailed in BS EN ISO 22475-1, namely the Sherbrooke sampler and the Laval sampler. The former appears to have been most widely used for sampling soft cohesive deposits or peat. BS EN ISO 22475-1 defines these samplers as Category A and capable of achieving Class 1 samples.*

The equipment to be used and the procedure to be followed for recovering block samples with a large sampler should be carried out in accordance with BS EN ISO 22475-1, Annex C, C.15.

## 25.11 Handling and labelling of samples

### 25.11.1 General

Samples are expensive to obtain and should be treated with great care. The usefulness of the results of the laboratory tests depends on the quality of the samples at the time they are tested, so a procedure should be established for the handling and labelling of the samples, as well as their storage and transport, both to prevent their deterioration and to ensure that they can be readily identified and drawn from the sample store when required.

The samples should be protected from frost, which would damage them, and from excessive heat and temperature variation, which could lead to deterioration in the sealing of the sample containers and subsequently damage the samples. The temperature of the sample store is influenced by the climate, but Class 1 and Class 2 samples should be stored at the lowest temperature practicable within the range 4 °C to 25 °C or as specified. Samples for chemical and environmental testing have different storage temperature requirements (see BS 10175 and BS ISO 18512).

Handling, transport and storage of samples should conform to BS EN ISO 22475-1:2006, Clause 11.

### 25.11.2 Labelling

All samples should be labelled with a unique reference number immediately after being taken from a borehole or excavation. If they are to be preserved with their natural water content, they should be sealed in an airtight container or coated in wax at the same time. The label should show all necessary information about the sample. If the sample is of ground that might contain hazardous substances, then the label should carry a warning to that effect.

The sample should be recorded on the daily field report. It should carry more than one label or other means of identification so that the sample can still be identified if one label is damaged. The label should be permanently marked and be sufficiently robust to withstand the effect of its environment and the transport of the sample.



*NOTE* The use of electronic labelling and tracking systems (barcode or chip) is now an available technology that facilitates more efficient traceability of samples. It might also provide the opportunity for initiating the electronic capturing of data in the field for subsequent use in the reporting process.

### 25.11.3 Disturbed samples of soil and hand specimens of rock

Where samples are required for testing, or where it is desirable to keep them in good condition over long periods, they should be treated as follows.

Immediately after being taken from a borehole or excavation, the sample should be placed in a non-corrodible and durable container of at least 1 L capacity, which the sample should fill, with the minimum of air space. The container should have an airtight cover or seal so that the natural water content of the sample can be maintained until tested in the laboratory.

*NOTE* For rock samples, an alternative procedure is to cover the sample in muslin or similar material and then coat in layers of paraffin wax. A microcrystalline wax is preferred because it is less likely to shrink or crack.

Larger disturbed samples that are required for certain laboratory tests may be packed in robust containers or plastic sacks.

A label, as described in 25.11.2, should be placed inside the sample container. An identical label should also be securely fixed to the outside of the container under a waterproof seal (wax or plastics). The containers may be crated during transit. During the interval when the samples are on site or in transit to the sample store, they should be protected from frost and from excessive heat.

For hand samples of rock, the reference number should be recorded by painting directly on the surface of the sample or attaching a label. Samples should then be wrapped in several thicknesses of paper and packed in a wooden box. A label of the type described in 25.11.2 should be included in the wrapping.

### 25.11.4 Samples taken with a tube sampler

#### COMMENTARY ON 25.11.4

*The following recommendations are applicable to all samples taken with tube samplers. The precautions for handling and protection of samples are to be regarded as a minimum requirement for samples taken by the usual methods. In special cases it might be necessary to take more elaborate precautions.*

Immediately after the sample has been taken from the boring or excavation, the ends of the sample should be removed to a depth of about 25 mm and any obviously disturbed soil in the ends of the sampler should also be removed. Several layers of molten wax, preferably microcrystalline wax (because it is less likely to shrink or crack), should then be applied to each end to give a plug of about 25 mm in thickness. The molten wax should be as cool as possible. The sides of the tube should be clean and free from adhering soil. If the sample is very porous, a layer of waxed paper should first be placed over the end of the sample.

Any remaining space between the end of the tube or liner and the wax should be tightly packed with a material that is less compressible than the sample and not capable of extracting water from it. There should be a close-fitting lid or screw-cap on each end of the tube or liner. If necessary, the lids should be held in position with adhesive tape.

In accordance with 25.11.2, a label bearing the number of the sample should be placed inside the container just under the lid. The label should be placed at the top of the sample. In addition, the number of the sample should be painted on the outside of the container, and the top or bottom of the sample should be indicated. The liners or containers should be packed in a way that minimizes damage by vibration and shock during transit.

### 25.11.5 Rotary core samples

Handling of rotary cores and any sub-samples required for laboratory testing is an integral part of the extrusion and preservation process and should be carried out in accordance with 25.7. Core boxes should be labelled to fully identify their content and any liners placed within the boxes should be marked with the depth range. Sub-samples for laboratory test should be labelled and also marked so as there is no doubt about which is the upper and lower end.

For each section of core removed from the core box for laboratory testing, a circular plastic pipe (or similar rigid material) of similar diameter to the core should be used to fill the gap left by the removed core sub-sample. This plastic pipe or similar rigid object should be marked to show the length of core removed and the top and base depths of the removed core. The reason for this marker is twofold; firstly to indicate where core has been removed from the stratigraphic sequence and secondly to prevent the remaining core from sliding within the box. This assists in helping to maintain the cores quality class 1.

The samples should be kept in a sample store as described in 25.11.1. It might be necessary to place rotary core samples in rigid liners to protect their structural integrity during handling and transportation. If samples are handled and transported in core boxes these might need to be packed to prevent being damaged by moving around in the box.

### 25.11.6 Block samples

After labels have been attached to the sample to indicate its location and orientation, the sample should be covered in muslin and then coated with a succession of layers of molten microcrystalline wax; these could be reinforced with layers of porous fabric (e.g. muslin) or plastic film. Additional labels should be fixed to the outside of samples. The sample should be packed in a suitable material and placed in a strong box or crate. Large samples should be protected with tight-fitting formwork or packed in rigid cement, expandable spray foam or wax or resin to prevent fissures from opening up under the weight of the samples.

## 26 Groundwater monitoring and sampling

### 26.1 General

#### COMMENTARY ON 26.1

*The determination of groundwater levels and associated water pressures is extremely important, because these have a profound influence on the behaviour of the ground during and after the construction of engineering works. Various strata, particularly those separated by relatively impermeable layers, can have different groundwater pressures, some of which might be sub-artesian or even artesian.*

*The location of permeable water-bearing strata and the measurement of water pressure in each stratum is particularly important where deep excavation or tunnelling is required, since special measures might be necessary to control the groundwater.*

*Accurate groundwater pressure measurement usually requires the installation of piezometers. The groundwater pressure might vary with time owing to seasonal (rainfall), tidal, anthropogenic or other causes, and it might be necessary to take measurements over an extended period so that such variations are investigated.*

*The efficient design of drainage works often requires determination and use of the contours of the water table or piezometric surface to ascertain the direction of the natural drainage, the seasonal variation and the hydrological controls.*

*Information on groundwater quality is relevant to the design of concrete foundations, and to assessments of the extent of any groundwater contamination and the risks it might pose to the water environment.*

The groundwater regime should be determined as part of an investigation; this might require in-situ permeability testing (see Section 7), the installation and monitoring of groundwater measuring instrumentation (see Section 8) for use in the measurement of groundwater levels and direction of flow, and the assessment of aspects of groundwater quality.

Sampling and monitoring of groundwater quality should be carried out in accordance with, as appropriate, BS 8550, BS EN ISO 5667-1, BS EN ISO 5667-3, BS ISO 5667-11 and BS ISO 5667-22.

Investigations of groundwater in connection with the assessment of potential risks to the water environment should be carried out in accordance with BS 10175, which provides guidance on the development of suitable sampling and monitoring strategies and how to implement them including the location and design of monitoring wells, how to take samples and their conservation and analysis.

## 26.2 Observations during drilling boreholes and excavating pits

Water level entries into boreholes (by whatever drilling method) and excavations (trial/observation pits and trenches) should be recorded.

Boreholes are not necessarily completed in a single continuous operation; they can take several days to reach the required depth and progress is suspended overnight. The water level in the borehole should be measured and recorded, along with the details of any casings, at the beginning and end of each shift.

The level of water measured in a borehole during or shortly after the completion of drilling is often used to ascertain the groundwater pressure; this should, however, be treated with great caution, because frequently insufficient time is allowed for the water level to stabilize, particularly as the drilling might have disturbed the pressures in the ground around the borehole. Moreover, the levels from which the water is entering the borehole might not always be known, because these are affected by the use of temporary borehole casings. For most conditions, an observation well or piezometer should be used in preference (see 26.3 and Section 8).

All observations during drilling should be reported together with the datum used for groundwater level measurements.

*NOTE Water level and casing observations also form part of the required information given in the sampling and in-situ testing standards.*

## 26.3 Observations in installations

Following drilling or excavation, observation wells or piezometers should be installed as appropriate to provide the opportunity for longer term monitoring to establish the groundwater levels under a range of conditions (e.g. long term, seasonal and tidal variations or during construction). A programme of regular measurements should be established, which might extend well beyond the period for intrusive investigation activities, and should be continued until the groundwater levels and variations of groundwater levels or pressures have been established with confidence.

*NOTE The design and construction of the monitoring installations is covered in Clause 52.*

## 26.4 Groundwater sampling

### COMMENTARY ON 26.4

*Groundwater samples are generally recovered and tested for the following reasons:*

- *construction related, typically as part of the assessment of the aggressiveness for buried concrete or corrosive action on metals; or*
- *geoenvironmental for investigating the presence of groundwater contamination.*

*Water samples collected from trial pits and boreholes at the time of their formation are unlikely to provide as reliable a representation of groundwater quality as those from permanent installations. However, such samples can provide some preliminary information which assists in the design of a subsequent groundwater monitoring programme.*

### 26.4.1 General

Groundwater sampling should be carried out in accordance with BS EN ISO 22475-1 or BS ISO 5667-11. Samples should be collected using a method appropriate to the data quality objectives, depth to groundwater, well performance, sample requirements and the parameters to be determined.

*NOTE 1 Sampling of water from discrete depths within a borehole might be required. This can be achieved by the use of packer seals to isolate the required sections, the use of samplers capable of taking samples from predetermined depths or the installation of multiport instruments from which to sample. Common methods for taking samples include (disposable) bailers, passive sample collectors, inertia pumps, submersible pumps and low-flow techniques including peristaltic and bladder pumps. The most appropriate technique is a site-specific decision. Where a permanent sampling pump is installed, samples of groundwater can be readily collected at intervals over a period of time, for example, to identify gradual changes in groundwater quality.*

Samples of groundwater should be analysed for pH, dissolved oxygen, temperature and conductivity in the field. Other parameters, for example nitrite, may also be determined in the field. The advice of the analytical laboratory should be obtained, and the laboratory should be informed of any field results.

Water level and depth of well measurements should be taken after sampling in order to avoid disturbance of the water column. The datum from which groundwater levels and borehole depths are measured should be recorded (e.g. ground level, top of the casing).

Where it is necessary to obtain samples of pore water in the unsaturated zone, special equipment, such as a piezometer with a ceramic or plastic tip, should be installed. Care should be taken to avoid the installation penetrating the saturated zone. Alternatively, a large undisturbed soil sample may be collected and the pore water removed by filtration, or by using a diaphragm or centrifuge.

Where practicable, groundwater should be characterized using data from a series of sampling operations. For example, a number of samples should be taken over a relatively short period, and then less frequently over a longer period. The periods between sampling events should be dependent on the findings of the earlier sampling operations. In addition, the sampling frequency should be based on the temporal and spatial variations in the quality of the groundwater and its flow.

*NOTE 2 Changes in the quality of groundwater are usually much more gradual in time and space than those in surface waters. In some aquifers, factors producing seasonal variations in quality could exist. Groundwater levels vary during the year in response to a variety of factors, including changing weather conditions and plant transpiration rates. Obtaining a full picture of annual variations requires monitoring over 12 months and could require several years. Groundwater levels can also fluctuate during the day due to tidal influences. The timing of sampling can be adapted to take into consideration known or expected fluctuations in groundwater levels (for example, due to tidal influence), flow directions, etc. Continuous monitoring of pH, temperature and electrical conductivity can provide a useful means of monitoring the need to increase or decrease the sampling frequency. In cases where there has been a considerable change in any of the parameters, it is advisable to consider extending the range of parameters being monitored.*

#### 26.4.2 Sampling during excavation and drilling

Water samples should normally be obtained as excavations are dug or boreholes are drilled. They can be used for screening for the presence of groundwater contamination and to establish whether it is necessary to install monitoring wells. However, caution should be applied when considering the analytical data from such samples, since the ground disturbance caused by digging can affect the composition of the water sample.

Care should be taken to ensure that any groundwater samples that are taken from boreholes during drilling are representative of the water-bearing stratum and have not been altered by water entering the borehole from other strata, or by contact with any water or drilling fluid used to advance the borehole. The depth and method of sampling, as well as the subsequent storage and handling of samples, can influence the results of analyses undertaken on groundwater samples.

When groundwater samples are to be taken from a stratum that has been in contact with drilling fluids or tools, all water-bearing strata from higher levels should first be sealed off by borehole casings. As far as possible, all the water in the borehole should be removed by bailing or pumping and the sample taken from water that collects by seepage.

*NOTE The water can contain a substantial amount of suspended particles that require field filtration or settlement before analysis. To overcome this, a larger volume of water may be taken to compensate for the volume of material removed by settlement or filtration.*

#### 26.4.3 Sampling from installations

Some investigations need the use of permanent monitoring wells from which groundwater samples can be taken at various times; in these circumstances, the monitoring wells should be constructed, installed and developed in accordance with Clause 52.

One of the most important aspects of sampling is to ensure that the sample is as representative as possible of the in-situ conditions. Purging should immediately precede any sampling, to remove stagnant water; water within a monitoring well that has not been recently purged is not always representative of water in the surrounding strata for a variety of reasons, including oxidation and loss of volatiles.

The impact of purging should be assessed alongside the benefits of improved sample integrity taking into account the purpose of the sampling exercise, data quality objectives and well recharge/performance when deciding on the most appropriate purging and sampling technique.

*NOTE 1 There might be circumstances (e.g. when volatile contaminants are present) when purging is not appropriate. In such cases, micro-purging (see Note 4) may be considered. In addition, or alternatively, samples of pre- and post-purge water may be collected during the early stages of an investigation to compare results. This information can then be used to optimize subsequent sampling.*

Purging should be undertaken at a flow rate less than that used for development of the well and greater than that proposed for sampling. The volume of water to be purged should vary according to the monitoring well type, its construction and the hydrogeological conditions. The purge volume is dependent on the design of the monitoring point, e.g. the diameter and depth of the water column. The water level should, therefore, always be measured prior to purging. Additionally, measurement of the water level during purging can give an indication of the drawdown.

To ensure that purging has been effective, monitoring of chemical parameters, such as electrical conductivity (EC), pH, temperature, redox potential (Eh), dissolved oxygen (DO) turbidity and specific parameters, should be carried out during the purging operation. A flow cell may be used for measurement of these parameters. As a minimum, EC should be measured. When using micro-purging techniques, purging should continue until successive readings of conductivity, pH and temperature have stabilized.

*NOTE 2 Guidance on groundwater purging volumes and strategies is provided in BS ISO 5667-11.*

*NOTE 3 If the well purges dry prior to sufficient water being removed, it might need to be allowed to recharge before later sampling.*

The method of disposal of the purged water should be selected carefully as the purged water might not be suitable for re-introduction into the borehole or to be allowed to drain to ground or the local drainage system. The use of low-flow purging or micro-purging may be used to reduce disposal volumes.

*NOTE 4 Low-flow purging or micro-purging is where the water column above the pump intake is not disturbed and water is drawn locally at a very low flow rate. Purging by this means may be carried out using a non-displacement pump (such as a bladder pump) at a flow rate that minimizes drawdown to the system. Typical flow rates at the pump intake for both low-flow purging and sampling are in the order of 0.1 L/min to 0.5 L/min, depending upon the site-specific hydrogeology.*

Micro-purging should be carried out using dedicated pumps, as passing a pump through the water column causes mixing and disturbance. Bailers, grab samplers and inertial pumps should not be used for micro-purging.

## 26.5 Sample containers, storage and transport

Any sample container used should be "inert", i.e. should not cause contamination of the sample, should not absorb any sample components (for example, organic compounds) and should not allow losses of volatile components. Except where there are other recommendations (see Note 1 and BS 10175), about 1 L of water should be collected in a clean PET (polyethylene terephthalate), polyethylene, polypropylene or glass bottle, which should be rinsed three times with the water being sampled before filling. Containers should be completely filled with the water so as to minimize contact with the air.

The samples should be transported and stored in the dark, at 4 °C to 6 °C and tested as soon as possible after sampling to minimize any potential for chemical and biological changes before examination, and in any case within 24 hours for time-dependent analytes such as COD and BOD.

*NOTE 1 More stringent requirements might apply in certain circumstances, particularly when accurate or extensive chemical testing is to be undertaken in order to investigate possible chemical contamination. Additional requirements could include special sampling techniques, multiple samples in different sample containers with different fixing agents, duplicate sampling, and special sample handling procedures.*

*NOTE 2 More information on appropriate sampling procedures, preservatives and containers for waters is given in BS ISO 5667-1 and BS ISO 5667-3.*

## Section 5: Geophysical field investigations

### 27 General

The acquisition of geophysical data should be considered as part of any ground investigation and as an input to the ground model in combination with intrusive investigations. The interpretations of the geophysical data should be validated against all the available ground data. Geophysics should be used to:

- map sub-surface geology and groundwater;
- locate geological anomalies such as faults and voids or man-made anomalies such as shafts and buried structures;
- measure physical and/or engineering properties of the ground; and
- detect potential hazards, for example unexploded ordnances (UXOs) and utilities.

Early thought should be given to the applicability of geophysical methods to the various aspects of the ground investigation programme, for example, to assist in the siting of boreholes, trial pits, etc.

*NOTE The choice of the correct geophysical method or combination of methods is essential to maximize the success of the survey and obtain the desired geological information in a cost-effective manner.*

### 28 The use of geophysical surveys as part of a ground investigation

A geophysical survey should be planned to detect a particular feature, such as a geological structure, or the distribution of ground water. Geophysical surveying can be a useful “reconnaissance” tool to obtain an overview in areas where little is known about the subsurface or for interpolation between intrusive investigation points. The specific techniques to be deployed, and details of how they are to be used should be tailored to the physical properties that need to be measured, and the resolution and depth of investigation required. The survey results should be processed and interpreted using all available geophysical data, direct observations from boreholes and/or sampling, to input to the evolution of the interpretative ground model.

*NOTE 1 The interpretation for some geophysical techniques might additionally involve a process of inverse modelling, enabling a consistency check of the assumptions made during the development of the interpretative model.*

Each geophysical technique detects contrasts in a particular physical property and, therefore, a particular volume of ground should be investigated in different ways, using a combination of two or more geophysical or intrusive techniques, to build up a complete and accurate picture. Where warranted by the complexity of the site, the use of a combination of geophysical data sets can allow a more detailed and robust interpretation to be made. Subsequent data from borehole records or exploratory excavations should be used to add detail to this information and constrain the geophysical interpretations.

The geophysical survey should be implemented and interpreted by expert personnel and should be entrusted to an organization specializing in this work. The expert geophysical advisor (such as an engineering geophysicist with chartered status) should approve all survey designs and interpretative reports.

The geotechnical adviser should provide the geophysical expert with all information relevant to the requirements and planning of the geophysical survey.



*NOTE 2 The principal role of the geophysical expert is to understand the requirements of the geotechnical adviser in terms of the information required from the geophysical investigation and the purpose for which the information is required. This understanding forms the basis of their advice regarding the possible use of geophysical techniques to reliably provide the required information to an accuracy suitable for the intended purpose.*

## 29 Geophysical techniques

### COMMENTARY ON CLAUSE 29

*There are many different geophysical techniques, each based on different theoretical principles, such as seismic velocity or electrical resistivity, and consequently each produces different sets of information relating to the properties of subsurface materials.*

*Geophysical techniques can be used on land, at sea and in the air. In each case basic techniques are modified, but the same physical properties are involved irrespective of the environment.*

Geophysical surveys can offer considerable savings in both time and money within investigations, and/or can significantly reduce the risk of encountering unforeseen ground conditions during construction; the benefits of a reconnaissance geophysical survey should be assessed at an early stage in a ground investigation to assist the planning of the subsequent intrusive investigation. This early survey can identify areas of the site where anomalous data are obtained, and which should be investigated by intrusive investigation. On sites where contamination is suspected, a geophysical survey may be carried out to form part of a preliminary risk assessment prior to drilling or sampling. Geophysical surveys may also be used to check the interpretation of the geological structure between the boreholes during the drilling programme. Later in the ground investigation, further geophysical surveys may be carried out within and between the boreholes and on the ground surface; these can determine the geological, hydrogeological and geotechnical properties of the ground mass.

The design of a geophysical investigation should take into account and incorporate, as appropriate, the four primary objectives of engineering geophysical surveys which are listed in Table 5. These are as follows:

- a) geological investigation;
- b) resource assessment;
- c) determination of engineering properties of the ground; and
- d) buried artefacts.

The applicability of the various methods for different geotechnical problems should be taken into account; a usefulness rating of the geophysical techniques is given in Table 6.

*NOTE 1 Further details of the various geophysical methods to which reference is made in this section can be found in Telford et al., 1990 [35], Dobrin and Savit, 1988 [36], Kearey and Brooks, 1990 [37], Milsom, 1996 [38], Parasnis, 1986 [39] and Reynolds, 1997 [40].*

*NOTE 2 A detailed consideration of the use of geophysical techniques in civil engineering applications is given in Styles, 2012 [41].*

Table 5 Geophysical methods in ground investigation (1 of 2)

| Problem                  |  | Example   | Methods and remarks  |
|--------------------------|--|---|--|
| Geological investigation | Lithological   | Soils over rock:<br>i) Sands and gravel over rock, water table low in sands and gravels<br>ii) Sands and gravels overlying clay, water table high in sands and gravels<br>iii) Clay over rock | <i>Land</i><br>Seismic refraction<br><br>Resistivity<br><br>Resistivity or seismic refraction<br>Shear-wave seismic reflection profiling |
|                          |  | Sediments over rock   | <i>Marine</i><br>Continuous seismic reflection profiling<br>Continuous resistivity profiling   |
|                          | Erosional (for caverns, see "Shafts..." below)                 | Buried channel  | Seismic refraction<br>Resistivity for feature wider than depth of cover  |
|                          |  | Buried karstic surface  | Resistivity contouring<br>Cross-hole seismic methods   |
|                          | Structural   | Buried faults, dykes  | Resistivity contouring<br>Seismic reflection or refraction<br>Magnetic and gravimetric (large faults)                                    |
| Resource assessment      | Water  | Location of aquifer<br>Location of saline/potable interface   | Resistivity and seismic refraction   |
|                          | Sand and gravel  | Sand, gravel over clay<br>Gravel banks  | <i>Land</i> . Resistivity<br><i>Marine</i> . Continuous seismic profiling, side scan sonar, echo sounding                                |
|                          | Rock   | Intrusive in sedimentary rocks  | Magnetic   |
|                          | Clay   | Clay pockets  | Resistivity (weathering might give low resistivity)  |
| Engineering properties   | Modulus of elasticity, density and porosity<br>Depths of piles | Dynamic deformation modulus<br>Check on effects of ground treatment   | Seismic velocity at surface, or with single or multiple boreholes. (Crosshole transmission.) Borehole geophysics.                        |
|                          | Rock rippability   | Choice of excavation method   | Seismic  |
|                          | Corrosivity of soils   | Pipeline surveys  | Surface resistivity. Redox potential   |

Table 5 Geophysical methods in ground investigation (2 of 2)

| Problem                |  | Example   | Methods and remarks  |
|------------------------|--|---|--|
| Buried artefacts       | UXO  | Any site development                            | Magnetometer, Electromagnetic (EM)   |
|                        | Cables and pipes                           | Trenches on land                                | Magnetometer, GPR<br>Electromagnetic field detectors   |
|                        | Submarine cables and pipes                 | Submarine trenches                              | Echo sounding, side scan sonar   |
|                        |  | Submarine pipelines                             | Side scan sonar, magnetic, continuous seismic profiling (especially if thought to be partially buried) with high frequency pinger                                |
|                        | Shafts, adits and caverns                  | Shaft, sink holes, mine workings                | Resistivity. Magnetics, electromagnetic, radar; infra-red air photography on clear areas<br>Crosshole seismic measurements<br>Detailed gravity for large systems |
| Archaeological remains | Foundations, buried walls, crypts, ditches | Magnetic, electromagnetic resistivity and radar |  |

Table 6 Usefulness of engineering geophysical methods (1 of 2)

| Geophysical method                               | Geotechnical applications |              |           |                 |                     |                        |         |            |                  |                  |
|--|---------------------------|--------------|-----------|-----------------|---------------------|------------------------|---------|------------|------------------|------------------|
|  | Depth to bed-rock         | Stratigraphy | Lithology | Fractured zones | Fault displacements | Dynamic elastic moduli | Density | Ripability | Cavity detection | Buried artefacts |
| <b>Seismic</b>                                   |                           |              |           |                 |                     |                        |         |            |                  |                  |
| – Refraction                                     | 4                         | 4            | 3         | 3               | 4                   | 3                      | 1       | 4          | 1                | 1                |
| – Reflection: land                               | 2                         | 2            | 2         | 2               | 4                   | 2                      | 0       | 1          | 2                | 1                |
| – Reflection: marine                             | 4                         | 4            | 2         | 2               | 4                   | 0                      | 0       | 1          | 1                | 2                |
| – Crosshole                                      | 2                         | 2            | 3         | 3               | 1                   | 4                      | 1       | 2          | 3                | 2                |
| <b>Electrical</b>                                |                           |              |           |                 |                     |                        |         |            |                  |                  |
| – Resistivity tomography                         | 4                         | 3            | 3         | 2               | 3                   | 0                      | 0       | 1          | 2                | 2                |
| – Induced polarization (IP)                      | 2                         | 2            | 3         | 1               | 0                   | 0                      | 0       | 0          | 0                | 0                |
| – EM and resistivity profiling                   | 3                         | 2            | 2         | 4               | 1                   | 0                      | 0       | 0          | 3                | 4                |
| <b>Other</b>                                     |                           |              |           |                 |                     |                        |         |            |                  |                  |
| – Ground probing radar                           | 2                         | 3            | 1         | 2               | 3                   | 0                      | 0       | 0          | 3                | 4                |
| – Gravity  | 1                         | 0            | 0         | 0               | 2                   | 0                      | 2       | 0          | 4                | 1                |
| – Magnetic                                       | 0                         | 0            | 0         | 0               | 2                   | 0                      | 0       | 0          | 2                | 4                |
| <b>Borehole</b>                                  |                           |              |           |                 |                     |                        |         |            |                  |                  |
| – Self-potential                                 | 2                         | 4            | 4         | 1               | 1                   | 0                      | 0       | 0          | 1                | 1                |
| – Single point resistance                        | 2                         | 4            | 4         | 0               | 0                   | 0                      | 0       | 0          | 0                | 0                |
| – Long and short normal, and lateral resistivity | 2                         | 4            | 4         | 0               | 0                   | 0                      | 0       | 0          | 0                | 0                |
| – Natural gamma                                  | 2                         | 4            | 4         | 0               | 0                   | 0                      | 0       | 0          | 0                | 0                |
| – Gamma-gamma                                    | 3A                        | 4            | 4         | 0               | 0                   | 0                      | 3A      | 0          | 0                | 0                |
| – Neutron  | 2A                        | 4            | 4         | 0               | 0                   | 0                      | 3A      | 0          | 0                | 0                |
| – Fluid conductivity                             | 0                         | 1            | 0         | 0               | 0                   | 0                      | 1       | 0          | 2                | 0                |
| – Fluid temperature                              | 0                         | 0            | 0         | 1               | 0                   | 0                      | 0       | 0          | 1                | 0                |
| – Sonce (velocity)                               | 3                         | 4            | 2         | 3               | 0                   | 3                      | 2       | 1          | 2                | 0                |

**KEY**

0 = not considered applicable

1 = limited use

2 = used, or could be used, but not best approach, or has limitations

3 = excellent potential but not fully developed

4 = generally considered an excellent approach, techniques well developed

A = in conjunction with other electrical or nuclear logs

Table 6 Usefulness of engineering geophysical methods (continued) (2 of 2)

| Geophysical method                               | Geotechnical applications |               |          |              |             |                            |                |                           |                 |                     |
|--|---------------------------|---------------|----------|--------------|-------------|----------------------------|----------------|---------------------------|-----------------|---------------------|
|  | Ground water exploration  | Water quality | Porosity | Permeability | Temperature | Flow rate and/or direction | Buried channel | Clay pockets in limestone | Sand and gravel | Basic igneous dykes |
| <b>Seismic</b>                                   |                           |               |          |              |             |                            |                |                           |                 |                     |
| – Refraction                                     | 2                         | 0             | 0        | 0            | 0           | 0                          | 4              | 1                         | 4               | 1                   |
| – Reflection: land                               | 2                         | 0             | 0        | 0            | 0           | 0                          | 4              | 3                         | 2               | 1                   |
| – Reflection: marine                             | 0                         | 0             | 0        | 0            | 0           | 0                          | 4              | 2                         | 2               | 0                   |
| – Crosshole                                      | 0                         | 0             | 0        | 0            | 0           | 0                          | 2              | 2                         | 1               | 2                   |
| <b>Electrical</b>                                |                           |               |          |              |             |                            |                |                           |                 |                     |
| – Resistivity tomography                         | 4                         | 4             | 2        | 1            | 0           | 0                          | 3              | 4                         | 3               | 2                   |
| – Induced polarization (IP)                      | 3                         | 1             | 3        | 2            | 0           | 0                          | 2              | 1                         | 1               | 1                   |
| – EM and resistivity profiling                   | 4                         | 4             | 1        | 0            | 0           | 0                          | 3              | 4                         | 3               | 3                   |
| <b>Other</b>                                     |                           |               |          |              |             |                            |                |                           |                 |                     |
| – Ground probing radar                           | 2                         | 3             | 1        | 2            | 3           | 0                          | 2              | 2                         | 3               | 3                   |
| – Gravity  | 1                         | 0             | 0        | 0            | 0           | 0                          | 2              | 0                         | 2               | 2                   |
| – Magnetic                                       | 0                         | 0             | 0        | 0            | 0           | 0                          | 0              | 1                         | 2               | 4                   |
| <b>Borehole</b>                                  |                           |               |          |              |             |                            |                |                           |                 |                     |
| – Self-potential                                 | 4                         | 2             | 0        | 0            | 0           | 0                          | 0              | 0                         | 0               | 0                   |
| – Single point resistance                        | 4                         | 2             | 1        | 0            | 0           | 0                          | 0              | 0                         | 0               | 0                   |
| – Long and short normal, and lateral resistivity | 4                         | 2             | 4        | 0            | 0           | 0                          | 0              | 0                         | 0               | 0                   |
| – Natural gamma                                  | 2A                        | 2             | 1A       | 3A           | 0           | 0                          | 0              | 0                         | 0               | 0                   |
| – Gamma-gamma                                    | 2A                        | 0             | 3A       | 2A           | 0           | 0                          | 0              | 0                         | 0               | 0                   |
| – Neutron  | 3A                        | 0             | 3A       | 2            | 0           | 0                          | 0              | 0                         | 0               | 0                   |
| – Fluid conductivity                             | 4                         | 4             | 4        | 1            | 0           | 0                          | 0              | 0                         | 0               | 0                   |
| – Fluid temperature                              | 2                         | 3             | 0        | 0            | 4           | 2                          | 0              | 0                         | 0               | 0                   |
| – Sonce (velocity)                               | 1                         | 0             | 1        | 0            | 0           | 0                          | 0              | 0                         | 0               | 0                   |

**KEY**

0 = not considered applicable

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3 = excellent potential but not fully developed

4 = generally considered an excellent approach, techniques well developed

A = in conjunction with other electrical or nuclear logs

## 30 Application of geophysical techniques

Interpretation of geophysical survey data should take account of prior knowledge of the site history and underlying geological structure derived from the desk study. For optimum interpretation of the data from a geophysical survey, adequate direct ground control should be available, such as boreholes or trial pits.

The geophysical data should be input to the ground model of the site to ensure a realistic correlation with the data. The overall model should be synthesized from all available geological information from the desk study, the intrusive investigation and field mapping to ensure that the model can be constrained and evaluated in practical terms. There should be close collaboration between the site geologists, engineers and geophysicists in the interpretation of the geophysical data.

The risks of the geophysical survey not returning the information required should be evaluated and discussed prior to the commissioning of the survey. In some cases, a feasibility study should be undertaken at the site to assess the suitability of the proposed geophysical techniques for the investigation of the geological problem.

The selection of geophysical methods in ground investigation should take account of five fundamental controlling factors:

- a) depth penetration;
- b) vertical and lateral resolution;
- c) signal-to-noise ratio;
- d) contrast in physical properties; and
- e) known limitations of the method.

*NOTE 1 All five factors are intimately linked and are particularly relevant in the field of engineering geophysics, where the small-scale nature of the engineering site puts increased demands on the accuracy of the final interpretation. For example, with the current range of operational equipment, some geophysical methods, such as ground probing radar, have limited penetration into the ground, but can achieve excellent resolution of the near-surface geological structures when significant penetration is achieved.*

*NOTE 2 Excessive environmental noise can adversely affect the results of seismic and electromagnetic surveys, for instance, and if the signal-to-noise ratio is too low the required signal might not be observed within the ambient noise, although the use of signal enhancement techniques can improve the results for data analysis.*

*NOTE 3 Most geophysical methods used in ground investigation relate to the location of a contrast in the physical properties of the materials under investigation, such as the distinct change in seismic velocity at the boundary between two geological strata, or a difference between the magnetic properties of the material in a disused mineshaft and those of the surrounding ground.*

*NOTE 4 In the modelling of geological structures, the best results are obtained when the geological conditions are uniform and simple with large clear-cut contrasts in the relevant physical properties of the formations, for example, strata on either side of a fault.*

Many geological boundaries are transitional, which can lead to a margin of uncertainty in the interpretation of the geophysical data when related to the engineering or geological boundary; for example, in a survey to determine the depth to competent rock, the results might be complicated by the presence of a weathered layer, or overlying boulders. The geophysical interpretation should indicate, and quantify where possible, the uncertainties that remain in the interpreted ground model.

In the location of geological hazards, such as natural cavities or buried mineshafts, geophysical surveying techniques should be laid out so that the area of anomalous ground conditions can be rapidly identified by comparison with data acquired over a known geological structure in the survey area.

On-site assessment of geophysical data should be encouraged to allow adjustment and optimization of the survey layout to improve the final product; this field assessment should be made by suitably qualified and experienced geophysicists. The increased capability for data review and numerical modelling should be balanced by an awareness that the quality of raw data has to be such as to warrant subsequent manipulations. The geophysical expert overseeing the acquisition phase should perform an on-going assessment of the quality of the data as it relates specifically to the purpose of the survey, and should liaise closely with the geotechnical adviser regarding the progress of the geophysical survey and the information the acquired data is expected to yield.

## 31 Specification and planning of a geophysical survey

### 31.1 General

The client or the geotechnical adviser should seek expert advice from an appropriately qualified geophysicist (see Clause 6) when considering the possible acquisition of geophysical data as part of a ground investigation. The geophysical expert may be an independent consultant engaged to act for the geotechnical adviser, or may be a senior technical expert in the specialist geophysical consultancy or contractor. The geotechnical adviser should be responsible for specifying the survey with significant relevant input from the geophysical expert.

*NOTE* If an inappropriate geophysical technique is specified and a rigid tender submission style called for, the client might not obtain the right information.

The recommendations given in 31.2 to 31.6 should be followed, where possible, when designing a geophysical investigation.

### 31.2 Geophysical trial survey

If there is any doubt about the feasibility of the geophysical investigation, a test or trial survey should be conducted to determine the appropriate method(s) and field techniques. Certain methods might be useful under one set of subsurface conditions but offer little or no information in others. The results of the trial geophysical survey should be used to refine the specification of the main survey or, in some cases, lead to a decision not to proceed with any further geophysical work.

### 31.3 Main geophysical survey

The main geophysical survey should include the following.

- a) The geophysical grids, traverse lines and sections should be set out and accurately located in space and elevation to a local or national datum.
- b) Data reduction and analysis should be undertaken in-step with the acquisition programme. Basic quality control should be undertaken during acquisition, and repeat measurements made immediately by the geophysicist as required. The geophysicist should analyse the data collected at the end of each day (or week, if more appropriate), make all check calculations possible, plot the data and evaluate it for consistency with other available data (geophysical, geological, borehole and pits) already to hand. This enables errors and inconsistencies to be identified and reacquired, if

necessary, to obtain better data. The survey programme can also be modified to take advantage of any newly obtained information.

- c) The raw field records should be kept for any subsequent re-evaluation or re-interpretation and should be made available to the client as required but these are not normally included in an engineering geophysical report. The records should be annotated and stored so that another geophysicist could receive them and proceed to an independent interpretation if necessary.
- d) The initial interpreted ground model derived from information earlier in the field programme should be reviewed and updated as necessary because the geophysical results are sensitive to features such as geological strike and topography.

*NOTE* For example, in a seismic refraction survey, the data in one direction might appear to indicate a simple two-layer situation, whereas the data for a traverse crossing perpendicularly could be best represented by a three-layer case, suggesting the possibility of a thin, "hidden-layer" of variable thickness.

The geophysical data set at a site should be treated as a whole and not piecemeal, as the premature or incomplete use of data acquired early in the survey programme can be misleading.

### 31.4 Integration with other aspects of the investigation

The programme for the investigation should be designed to include boreholes positioned to calibrate the interpreted ground model derived from the geophysical information and to obtain detailed information on specific problem areas indicated by geophysical anomalies. As additional subsurface information is obtained, the initial geophysical interpretation should be refined, and plans for the remainder of the investigation may be revised to optimally fill in the gaps in the required subsurface information. Downhole geophysical borehole logging should be used, where possible and appropriate, to further refine the geophysical interpretation and the resulting ground model.

If the borehole and the geophysical survey programmes are carried out at sites where small-scale geological features might be present, failure of the geophysical surveys to detect any such feature (e.g. a cavity or narrow zone of shearing in the rock mass) should not be taken to mean that such features do not exist.

### 31.5 Submission of report

The final report should incorporate all the geophysical results, presented in the agreed format and scales, together with any correlation with drilling results, etc. The report should typically contain the following:

- a) the remit and intended objective of the commissioned work;
- b) a statement of the information available at the start of the survey (e.g. from the desk study, field reconnaissance, ground investigations to date and previous geophysical surveys);
- c) details of the equipment and the acquisition parameters used;
- d) descriptions of any difficulties with equipment or environmental conditions or access that are relevant to the accuracy or coverage of the data acquired;
- e) the processing functions applied to the raw data before interpretation;
- f) a description and graphical representation of the interpretations made, illustrated by plots of all of the acquired data, or example sections of data as agreed, such that it is clear to the geotechnical adviser the basis upon which the interpretations have been made;



- g) the accuracy and resolution of the information derived from the survey, referencing borehole or other ground investigation data available as appropriate, referring in particular to the limitations of the information acquired; and
- h) recommendations for any further ground investigation (geophysical, or targeted intrusive).

### **31.6 Feedback of subsequently acquired data**

Any refinement of the ground model should include additional information derived from subsequent ground investigation work to provide constraints on the interpreted ground model previously derived from the geophysical survey. The geophysicist should update their interpretation with appropriate changes of the report and diagrams.

## Section 6: Description of soils and rocks

### 32 The description process

#### COMMENTARY ON CLAUSE 32

*Accurate descriptions of exposures (natural, in excavations, cores or samples) of soil and rock are an important aspect of ground investigation. The results of a ground investigation might be required long after the disposal of the samples when the descriptions are, in many cases, the only evidence remaining of what was discovered. In addition, designers often make use of past experience for materials of similar age, origin or condition based on the descriptions.*

*For some soils it might be difficult to obtain representative samples or to carry out field tests and, in such materials, the descriptions might form the main, or only, information on which the assessment of the behaviour of the ground is based.*

*The words cohesive and non-cohesive, or granular, are often used to distinguish soils that contain a significant proportion of fine grains and behave in a cohesive manner when subjected to quick loading from coarse-grained soils, which have no apparent cohesion. The word cohesive usually describes a soil which has an undrained strength measured in an unconfined compression test. In this test the strength arises from a combination of friction and negative pore pressure; cohesion, therefore, describes the ability of a soil to sustain a pore-water suction when unconfined.*

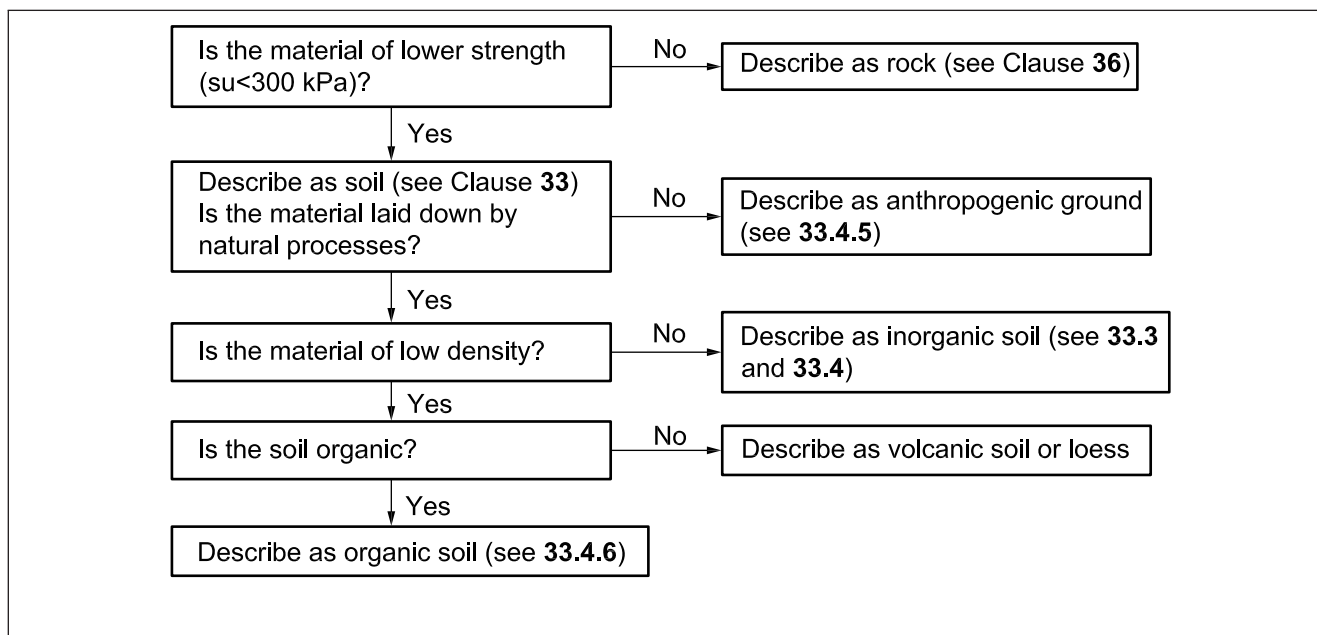
*All soils can be considered granular so, in terms of effective stress, true cohesion in any un-cemented soils is very small (most un-cemented soils slake when immersed in water). Moreover, any un-cemented soil can behave in either a cohesive manner or in a non-cohesive manner depending on the response of the pore pressure to loading. For example, saturated and dry clean sand is non-cohesive and can be poured, but partially saturated sand can behave in a cohesive manner and a cohesive strength can be measured. Under long-term, fully drained conditions, clays behave in a frictional, non-cohesive manner and it is the frictional properties of the soil that are relevant when assessing the long term stability of clay slopes.*

The description of soils and rocks should be carried out in accordance with BS EN ISO 14688-1 and BS EN ISO 14689-1 (further guidance is also given in Norbury, 2010 [42]).

The descriptive terms apply primarily to natural soils and rocks but may also be applied to many types of man-made materials (see 33.4.5 for further details).

Each category of natural and man-made materials outlined in Figure 5 should be described using the appropriate approach and terminology.

Figure 5 Selection of descriptive procedure for different materials



The process shown in Figure 6 for the identification and description of soils should be followed.

Descriptions should be made on samples recovered from boreholes and excavations and/or from examination of in-situ materials. The borehole log should aim to be as objective a record as possible of the ground conditions at the borehole position before the ground was subjected to disturbance and loss by the boring or excavation process. The degree of interpretation should be kept to a minimum. If interpretation is necessary to provide information, it should be clearly identified.

The level of detail that is required or appropriate in descriptions might vary; the level of detail should be established at the start of an investigation.

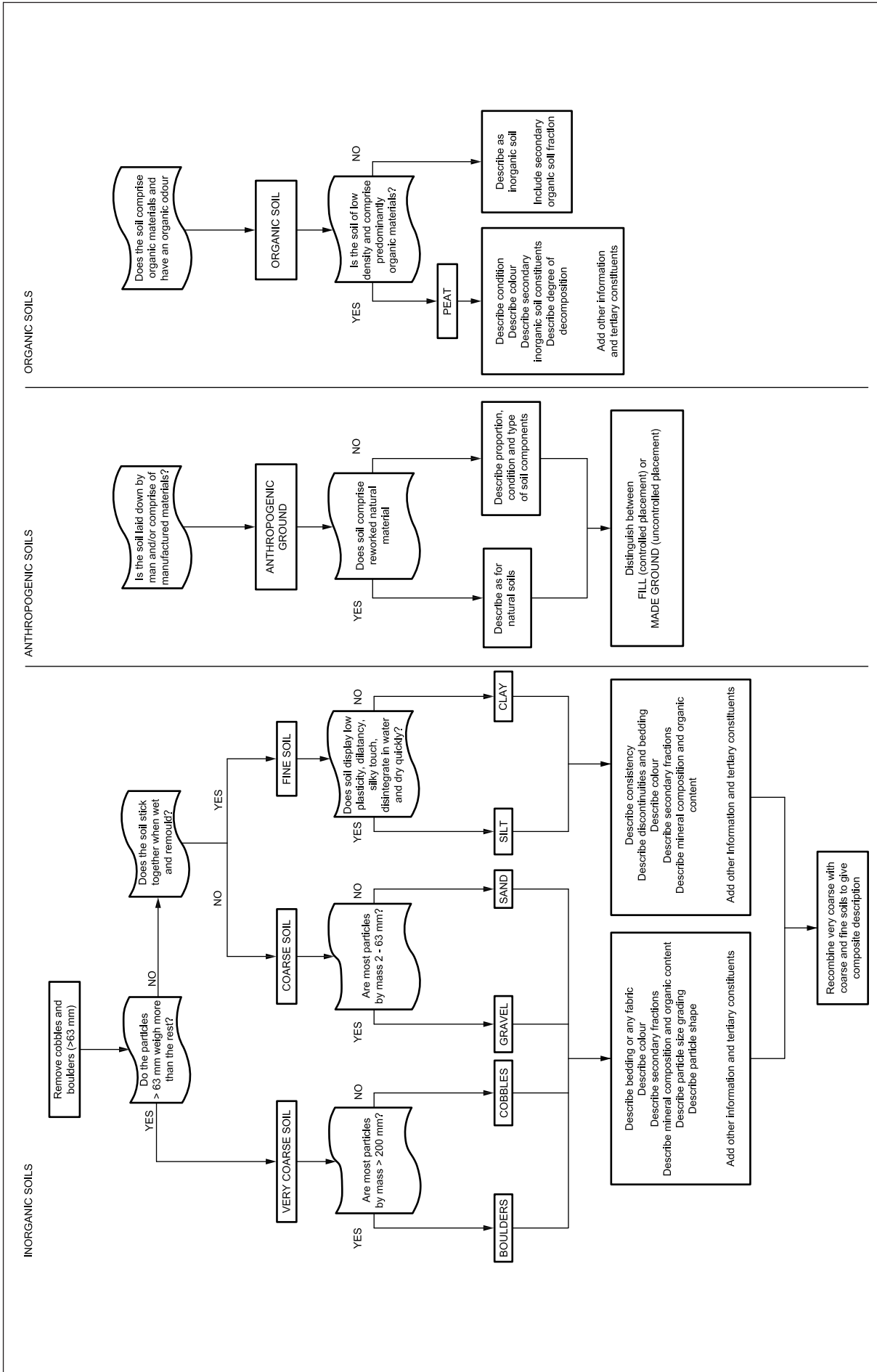
*NOTE 1* Adjectives such as “probably” or “possibly” are useful in this regard.

The reliability of sample descriptions in reflecting the in-situ characteristics depends greatly on the quality of the samples and the level of detail in the description should reflect this quality. Any doubts as to the representativeness or reliability of the sample should be stated. An accompanying report should give the origin, type and quality of each sample.

Following description, soils and rocks may also be classified in accordance with BS EN ISO 14688-2 and BS EN ISO 14689-1. These classification terms should not generally appear on field records.

*NOTE 2* Classification (see Clause 34) provides additional guidance on the behaviour of a particular soil or rock by allowing comparison with behaviour encountered on other sites.

Figure 6 General identification and description of soils



## 33 Description of soils

### 33.1 The scope of soil description

The soil should be described in terms of material and mass characteristics, that is in terms of nature, state and structure.

- Nature of the soil grains: their particle size grading, shape and texture or, if appropriate, their plasticity, together with special features such as organic or carbonate content. The nature of a soil does not usually change during civil engineering works. Nature of the soil can be described on disturbed samples.
- State of the soil grains: their packing, water content, degree of saturation, strength or relative density, and stiffness. The state of a soil usually changes during civil engineering works; the description of the state of the soil requires undisturbed samples or exposures.
- Structure: all the features of a soil that are removed by reconstitution, i.e. fabric or microfabric features, such as bedding, discontinuities or cementing. Structure is often destroyed by large distortions, and so can be observed only in the field on natural or artificial exposures or, to some extent, in an undisturbed (Quality Class 1 or 2) sample.

Inorganic soils should be described as very coarse, coarse or fine. Table 7 shows the recommendations which are developed in more detail in the text.

*NOTE 1 Low density soils, as shown in BS EN ISO 14688-1:2002, Figure 1 can also include other inorganic soils such as loess and some chemically weathered residual soils.*

*NOTE 2 Very coarse soils are boulders and cobbles whereas coarse soils are gravels and sands. When saturated and unconfined, they cannot sustain negative pore pressures, so these soils do not have any undrained strength or apparent cohesion. Fine soils are clays and silts. When saturated they can sustain suctions in unconfined tests and so have an apparent cohesion. If well-graded soils contain a sufficient proportion of fine grains to fill the spaces between the coarse grains, they are described as fine soils; if well-graded soils contain insufficient fine grains to fill the spaces between the coarse grains, they are described as coarse soils. These distinctions based on grain size apply equally to natural soils and man placed and made materials.*

*NOTE 3 The terms coarse and fine are often loosely referred to as granular and cohesive. Use of the latter terms in this context is discouraged.*

Any description should acknowledge the quality of the sample by not over-describing the nature, state or structure, e.g. the state of a soil may not be described on a sample in which the water content is not representative.

The geological unit should be named where known as identified in the desk study, but might need updating as required by the ground investigation. Geological unit names should be used consistently throughout the investigation.

Table 7 Field identification and description of soils

| SOIL GROUP                    | Very coarse soils  |          |         |         | Coarse soils   |        |         |          | Fine soils   |           |            |             |   |  |  |  |
|-------------------------------|--|----------|---------|---------|--|--------|---------|----------|--|-----------|------------|-------------|---|--|--|--|
|                               | BOULDERS   |          | COBBLES |         | GRAVEL   |        | SAND    |          | SILT   |           | CLAY       |             |   |  |  |  |
| PRINCIPAL SOIL TYPE           | Large boulder  | Boulder  | Cobble  | Cobble  | Coarse   | Medium | Fine    | Coarse   | Medium   | Fine      | Coarse     | Medium      | Fine  |  |  |  |
| Particle size (mm)            | >630   | 630–200  | 200–63  | 200–63  | 63–20  | 20–6.3 | 6.3–2.0 | 2.0–0.63 | 0.63–0.2   | 0.2–0.063 | 0.063–0.02 | 0.02–0.0063 | 0.0063–0.002  |  |  |  |
| <b>Visual identification</b>  | Only seen complete in pits or exposures. Difficult to recover whole from boreholes.  |          |         |         | Easily visible to naked eye; particle shape can be described; grading can be described.  |        |         |          | Only coarse silt visible with hand lens; exhibits little plasticity and marked dilatancy; slightly granular or silky to the touch; disintegrates in water; lumps dry quickly; possesses cohesion but can be powdered easily between fingers. |           |            |             | Dry lumps can be broken but not powdered between the fingers; dry lumps disintegrate under water but more slowly than silt; smooth to the touch; exhibits plasticity but no dilatancy; sticks to the fingers and dries slowly; shrinks appreciably on drying usually showing cracks |  |  |  |
| <b>Density/Consistency</b>    | No terms defined. Qualitative description of packing by inspection and ease of excavation.   |          |         |         | Classification of relative density on the basis of N value (Table 10), or field assessment using hand tests may be made (Table 11).  |        |         |          | <b>Field test</b>  |           |            |             | <b>Field test</b>   |  |  |  |
| <b>Discontinuities</b>        | Describe spacing of features such as fissures, shears, partings, isolated beds or laminae, desiccation cracks, rootlets, etc. Fissured: Breaks into blocks along unpolished discontinuities. Sheared: Breaks into blocks along polished discontinuities.   |          |         |         | <b>Scale of spacing of discontinuities</b>   |        |         |          | <b>Term</b>  |           |            |             | <b>Term</b>   |  |  |  |
| <b>Bedding</b>                | Describe thickness of beds in accordance with geological definition. Alternating layers of materials are inter-bedded or inter-laminated and should be described by a thickness term if in equal proportions, or by a thickness of and spacing between subordinate layers where unequal.   |          |         |         | <b>Scale of bedding thickness</b>  |        |         |          | <b>Term</b>  |           |            |             | <b>Term</b>   |  |  |  |
| <b>Colour</b>                 | <b>HUE</b><br>can be preceded by <b>LIGHTNESS</b><br>and/or <b>CHROMA</b>  |          |         |         | Red / Pink / Orange / Yellow / Cream / Brown / Green / Blue / White / Grey / Black<br>Light / - / Dark<br>Reddish / Pinkish / Orangeish / Yellowish / Brownish / Greenish / Bluish / Greyish |        |         |          | Colours may be mottled<br>More than 3 colours is multicoloured   |           |            |             |   |  |  |  |
| <b>Secondary constituents</b> | For mixtures involving very coarse soils see 33.4.4.2  |          |         |         | <b>Term in coarse soils</b>  |        |         |          | <b>Term in fine soils</b>  |           |            |             | <b>Term in secondary constituents</b>   |  |  |  |
| <b>Mineralogy</b>             | Terms can include: glauconitic / micaceous / shelly / organic / calcareous. For example: slightly (glauconitic) / (glauconitic) / very (glauconitic)<br>Carbonate content: slightly calcareous – weak or sporadic effervescence from HCl / calcareous – clear but not sustained effervescence from HCl / highly calcareous – strong, sustained effervescence from HCl.<br>Organic soils contain secondary finely divided or discrete particles of organic matter, often with distinctive smell, might oxidize rapidly. For example: slightly organic – grey / organic – dark grey / very organic – black |          |         |         | <b>Proportion secondary<sup>A)</sup></b>   |        |         |          | <b>Proportion secondary<sup>A)</sup></b>   |           |            |             | <b>Proportion secondary<sup>A)</sup></b>  |  |  |  |
| <b>Particle shape</b>         | Very angular/Angular/Sub-angular/Sub-rounded/Rounded/Well-rounded<br>A dominant shape can be described, for example: Cubic/Flat/Elongate   |          |         |         | <b>Term in coarse soils</b>  |        |         |          | <b>Term in fine soils</b>  |           |            |             | <b>Term in secondary constituents</b>   |  |  |  |
| <b>PRINCIPAL SOIL TYPE</b>    | LARGE BOULDERS   | BOULDERS | COBBLES | COBBLES | GRAVEL   |        | SAND    |          | SILT   |           | CLAY       |             | CLAY  |  |  |  |
| <b>Tertiary constituents</b>  | Example terms include: shell fragments / pockets of peat / gypsum crystals / pyrite nodules / calcareous concretions / flint gravel / brick fragments / rootlets / plastic bags<br>Qualitative proportions can be given: with rare / with occasional / with numerous/frequent/ abundant. Proportions are defined on a site or material specific basis, or subjectively   |          |         |         |  |        |         |          |  |           |            |             |   |  |  |  |
| <b>Geological unit</b>        | Name in accordance with published geological maps, memoirs or sheet explanations. For example: RIVER TERRACE DEPOSITS / GLACIAL SAND AND GRAVEL / MADE GROUND / LANGLEY SILT MEMBER / WEATHERED CHARMOUTH MUDSTONE FORMATION / CLAY-WITH-FLINTS / LOWESTOFT FORMATION / EMBANKMENT FILL / ALLUVIUM / TOPSOIL / LAMINATED BEDS, WOOLWICH FORMATION / SHERWOOD SANDSTONE GROUP   |          |         |         |  |        |         |          |  |           |            |             |   |  |  |  |

A) Percentage coarse or fine soil type assessed excluding cobbles and boulders.

B) Gravelly or sandy and/or silty or clayey.

C) Can be described as fine soil depending on mass behaviour.

D) Gravelly and/or sandy.

E) Can be described as coarse soil depending on mass behaviour.

F) Gravelly or sandy.

### 33.2 The basis of soil description

#### COMMENTARY ON 33.2

*A soil's characteristics are based on the particle size grading of the coarser particles and the plasticity of the finer particles; these play a major role in determining the engineering properties of the soil and form the basis of the soil's description.*

A first appraisal of the physical properties relevant in the engineering context should be made from the visual description of the soil's nature and composition, assisted by a few simple hand tests (see Clause 34). Soils that stick together when wet and can be rolled into a thread that supports the soil's own weight (i.e. they have cohesion and plasticity) are matrix supported and should be described as fine soils (see BS EN ISO 14688-1:2002, Figure 1). Soils that do not exhibit these properties are clast supported and should be described as coarse soils.

*NOTE 1 The boundary between fine and coarse soils is on the basis of behaviour, not weight percentage.*

The principal soil type should first be determined as defined in Table 7, followed by description of the secondary and tertiary fractions and other features such as bedding, colour and particle shape.

*NOTE 2 The descriptive process is summarized in Figure 6 (see BS EN ISO 14688-1:2002, Figure 1).*

In a soil description, the main characteristics should be given using the following standard word sequence, as applicable (following the order of the rows in Table 7). The main description may be followed, where appropriate, by further details for clarity.

- a) mass characteristics comprising state and structure (see 33.3):
  - 1) relative density/consistency;
  - 2) discontinuities;
  - 3) bedding;
- b) material characteristics comprising nature and state (see 33.4);
  - 1) colour;
  - 2) composite soil types: particle grading and composition; shape and size;
  - 3) tertiary constituents either before or after the principal soil type as appropriate;
  - 4) principal soil type (name in capitals, e.g. SAND), based on grading and plasticity shape;
- c) stratum name: geological formation, age and type of deposit (see 33.5); classification (optional).

#### EXAMPLES:

- Firm closely fissured yellowish brown CLAY (LONDON CLAY FORMATION).
- Medium dense light greyish brown sandy slightly clayey subrounded fine to coarse GRAVEL of various lithologies with low cobble content. Cobbles are subrounded of strong sandstone (RIVER TERRACE DEPOSIT).
- Greenish brown gravelly fine to coarse slightly glauconitic SAND. Gravel is rounded fine and medium of black flint (BLACKHEATH MEMBER).
- Firm to stiff brown slightly sandy slightly gravelly CLAY with occasional lenses (5 mm by 15 mm to 15 mm by 50 mm) of yellow silty sand. Gravel is subangular to subrounded fine and medium of various lithologies (GLACIAL TILL).

Materials in interstratified beds may be described as follows:

- Thinly interbedded yellow fine SAND and soft grey CLAY (ALLUVIUM).

Any additional information on the secondary or tertiary constituents should be placed at the end of the main description after a full stop, to keep the standard main description concise and unambiguous.

### 33.3 Mass characteristics of soils

#### 33.3.1 Range of application

The mass characteristics of soils should also be given. Reference should be made to Table 7.

#### 33.3.2 Scale of consistency, strength and relative density

The consistency of clays and silts should be assessed in the field, as given in Table 7 and as follows in Table 8.

Table 8 Terms for description of consistency

| Field description term | Consistency description definition<br>[after BS EN ISO 14688-1:2002, 5.14]   |
|------------------------|--|
| Very soft              | Finger easily pushed in up to 25 mm  |
| Soft                   | Exudes between fingers<br>Finger pushed in up to 10 mm   |
| Firm                   | Moulded by light finger pressure<br>Thumb makes impression easily  |
| Stiff                  | Cannot be moulded by fingers, rolls in the hand to a 3 mm thick thread without breaking or crumbling<br>Can be indented slightly by thumb                        |
| Very stiff             | Crumbles in rolling a 3 mm thick thread, but can then be remoulded into a lump<br>Can be indented by thumb nail<br>Cannot be moulded but crumbles under pressure |

*NOTE 1* These subdivisions can be approximate, particularly in material of low plasticity.

*NOTE 2* The description of materials of higher consistency than very stiff should use rock strengths and material names.

*NOTE 3* Soils varying around the boundary between soil (very stiff consistency) and rock (extremely weak strength) can be described as, for example, "very stiff CLAY/extremely weak MUDSTONE". A boundary on the log at rockhead if it is a simple transition is preferable.

The description of consistency in silt should be made of a sample that is representative of the in-situ condition. The consistency terms given in Table 7 and Table 8 should be used.

*NOTE 1* Silts are conventionally described as fine soil, but depending on their grading, can behave as coarse soil. In these circumstances use of relative density terms rather than consistency might be appropriate.

Where the sample is disturbed but some guidance as to the in-situ consistency can be sensibly given, the consistency term should be given in brackets, e.g. (Probably firm) brown CLAY. No consistency term should be given when this would be unreliable.



*NOTE 2* Direct measurements of the undrained shear strength (e.g. field or hand vane, laboratory unconsolidated undrained triaxial test or laboratory vane) provide a classification of the undrained strength using the scale given in Table 9. This may be used in discussion of the material strength in the report text but does not form part of the soil description required for exploratory hole or exposure logs.

Table 9 Terms for classification of strength

| Term based on measurement | Undrained strength classification definition, $s_u$ , in kPa [from BS EN ISO 14688-2:2004, 5.3, Table 5] |
|---------------------------|--|
| Extremely low strength    | <10  |
| Very low strength         | 10 – 20  |
| Low strength              | 20 – 40  |
| Medium strength           | 40 – 75  |
| High strength             | 75 – 150   |
| Very high strength        | 150 – 300  |

Strength determination for a stratum should be given using a number of individual determinations by specified means, i.e. triaxial, laboratory vane and hand vane tests (see BS EN 1997-2:2007, Annex M, P and I).

*NOTE 3* The soil/rock boundary is set at an undrained shear strength of 300 kPa (an unconfined compressive strength of 0.6 MPa) (see BS EN ISO 14688-2 and BS EN ISO 14689-1). The field assessment of this boundary is not easy, being beyond the range of hand vanes, but such fine soils, in their saturated condition, break in a brittle manner and can only be scratched with a thumbnail.

If the soil includes fissures or other discontinuities the field consistency description should apply to the intact material between discontinuities. If a (lower) mass consistency which includes the effect of discontinuities can also be assessed in the field, this should be separately and clearly reported. Further information on the discontinuities should be given at the end of the main description, after a full stop for clarity.

*NOTE 4* The consistency and discontinuity terms are linked in the word order, giving, for example, "stiff fissured", "firm sheared".

If a mineral cement appears to be present the nature and degree of cementing should be noted, e.g. "slightly iron oxide cemented sand" or preferably using rock strength terms, e.g. "very weak carbonate cemented SANDSTONE".

*NOTE 5* It is also useful to note whether slaking occurs on immersing the air dry material in water.

Laboratory or field test results should also be used to provide a strength classification; however, the strength measured might not be representative of the stratum as a whole due to the effects of sampling disturbance, in-situ test disturbance and scale effects; these can lead to significant underestimation of field strength. Discrepancies between results of various tests used in strength measurements should be reported bearing in mind that the different tests involve different sample sizes, stress paths, strain rates and stress orientations. Strength classification terms should not be given on borehole logs.

*NOTE 6* Laboratory tests on fissured materials usually give lower results than the intact material strength.

*NOTE 7* The use of empirical relationships between standard penetration test "N" values and strength of fine soils might also be useful (see articles on the standard penetration test by Stroud and Butler, 1975 [43] and Stroud, 1989 [44]).

The relative density of sands and gravels should be determined in boreholes by N-values obtained from the standard penetration test and a classification in terms of N-values as shown in Table 10.

Table 10 Terms for classification of relative density

| Term         | Classification based on uncorrected SPT N-values for use of borehole logs |
|--------------|---|
| Very loose   | 0 – 4   |
| Loose        | 4 – 10  |
| Medium dense | 10 – 30   |
| Dense        | 30 – 50   |
| Very dense   | >50   |

The numerical SPT N-values on the log should be uncorrected (see *CIRIA R143* [45]) and the relative density classification term should be applied in accordance with Table 10. Particular care should be taken in applying these classification terms in coarse gravels; they should not be used for very coarse soils.

The relative density of coarse soils in observation pits and trenches may be assessed using the field tests given in Table 11. If the density is assessed in this manner, the results should be included together with the test method on the field log. The application of a relative density term should be provided as extra information after the main description, not as the first sentence of the description. For example, the material observed in an exposure could be described as:

- Grey silty SAND. Assessed as loose as fairly easy to excavate with a spade; or
- Brown very sandy GRAVEL. Assessed as medium dense using a geological pick.

The descriptive terms obtained in this way should not be confused with those obtained from the standard penetration test (SPT) in boreholes, but the source of the descriptor is obvious in practice. These field tests should not be used on borehole samples.

Table 11 Assessment of field density

| Density term | Excavation by spade or pick <sup>A)</sup>                                  | Penetration of light horizontal blows of geological pick | Penetration of geological pick by pushing |
|--------------|--|--|---|
| Very loose   | Very easy to excavate with a spade   | 100 mm (full depth)                                      | 75 mm – 100 mm (full length)              |
| Loose        | Fairly easy to excavate with a spade or to penetrate with a crowbar        | 50 mm – 100 mm   | 25 mm – 75 mm                             |
| Medium dense | Difficult to excavate with a spade or to penetrate with a crowbar          | 25 mm – 50 mm  | 10 mm – 25 mm                             |
| Dense        | Very difficult to penetrate with a crowbar. Requires a pick for excavation | 5 mm – 25 mm   | 2 mm – 10 mm                              |
| Very dense   | Difficult to excavate with a pick  | <5 mm  | <2 mm                                     |

<sup>A)</sup> See BRE, 1993.

### 33.3.3 Discontinuities

Discontinuities should be described in accordance with BS EN ISO 14688-1 and BS EN ISO 14689-1.

*NOTE* Discontinuity types include fissures and shear planes.

The spacing of discontinuities should be described using the spacing scale given in Table 7. Their surface texture, e.g. rough, smooth, polished, striated, should be described (see Table 7 and BS EN ISO 14689-1) as should any colour changes or staining on discontinuities and any infilling; infilling can be present, e.g. sand in vertical desiccation cracks within clay. Where possible in exposure, the orientation or trend of discontinuities should be given by stating direction of dip and angle of dip (e.g. 180°/40°); their persistence and openness should also be stated.

### 33.3.4 Bedding

Bedding should be described in accordance with BS EN ISO 14688-1. Layer boundaries are not always horizontal and can include irregular features that should be recorded, e.g. periglacial structures such as ice wedges.

The thickness of bedding units should be described using the terms in Table 7; in a homogeneous soil this is marked by bedding planes or, possibly, colour changes, and not necessarily discontinuities.

*NOTE* Interstratified deposits are those in which there are layers of different types of material, which might be of constant thickness, or might thin out locally or occur as lenses.

If beds of alternating or different soil types are too thin to be described as individual strata, the soil should be described as interbedded or interlaminated, using the terms in Table 7, as appropriate. Where the soil types are approximately equal, "thinly interlaminated SAND and CLAY" would, for example, be appropriate. Where one material is dominant, the subordinate material should be described with a bed thickness and a bed spacing (using the bedding and discontinuity spacing terms respectively), e.g. "SAND with closely spaced thick laminae of clay". Where two or more soil types are present in a deposit, arranged in an irregular manner, the soils should be described as mixed, e.g. "SAND with gravel size pockets (20 mm – 35 mm) of CLAY".

The spacing of sedimentary features, such as shell bands, and of minor structures, such as root holes in soils, should also be reported as measurements or using the spacing terms for discontinuities. There are descriptive terms that have no size connotation (e.g. pocket, lens, inclusion); where such terms are used their size, spacing and frequency should be defined and reported.

Any special bedding characteristics, e.g. cross-bedding, graded bedding, should be described besides disturbed bedding structures, including slump bedding or convoluted bedding.

### 33.4 Material characteristics of soils

#### COMMENTARY ON 33.4

*Material characteristics refer to those characteristics that can be described from visual and manual examination of either disturbed or undisturbed samples, and include soil name, colour, particle shape, particle grading and particle composition.*

#### 33.4.1 Range of application

Material characteristics of soils should be described in accordance with BS EN ISO 14688-1.

#### 33.4.2 Colour

The colour should be described using the terms given in Table 7. The colour description should be the overall impression of the damp soil. Strata with more than one distinct colour may be described, for example, as mottled, but strata with more than three distinct colours should normally be described as multicoloured. Where a soil is multicoloured, the colour assemblage should be recorded where this is important to identifying the geological unit to which the soil belongs, e.g. within the Lambeth Group. Colour changes due to oxidation or desiccation, for example, should be noted.

For a large majority of descriptions, a simple approach to colour description should be used (see Figure 7.3 of Norbury, 2010 [42]). For more detailed descriptions, colour charts such as those based on the Munsell colour system may be used (see *Munsell soil color charts* [46] and the Geological Society of America's *Rock color chart* [47]).

*NOTE Consistency of colour description is usually more important than absolute accuracy, and the use of reference samples or colour charts is useful in this regard.*

#### 33.4.3 Particle shape, grading and composition

Where appropriate, particle shape should be described by reference to the general form of the particles, their angularity (which indicates the degree of rounding at edges and corners) and their surface characteristics. The angularity and form terms are illustrated in Figure 7.

The following terms should be used where appropriate.

- a) Angularity:
- very angular;
  - angular;
  - subangular;
  - subrounded;
  - rounded;
  - well rounded;
- b) Form:
- cubic;
  - flat (or tabular);
  - elongate;
- c) Surface texture:
- rough;
  - smooth.

Angularity terms should be applied to particles of gravel size or larger; form may be described for extreme particle shapes. Any layering or preferred orientation of the particles should be recorded.

*NOTE 1 Occasionally the use of these terms might be of greater importance and used more fully, such as in an aggregate assessment study. "Flat" is preferred to the term "flaky", used in BS EN 933-3, where the shapes are illustrated. The surfaces of particles might be described, for example, as etched, pitted, honeycombed or polished.*

The distribution of particle sizes within sands and gravels should be described using the terms in Table 7, stating the predominant size fractions present, e.g. "fine and medium GRAVEL" or "fine to coarse SAND".

*NOTE 2 The absence of these adjectives means that fine, medium and coarse fractions are all present in roughly equal proportions; use of the conjunctions "and" or "to" allow differentiation between predominant fractions and a range of sizes.*

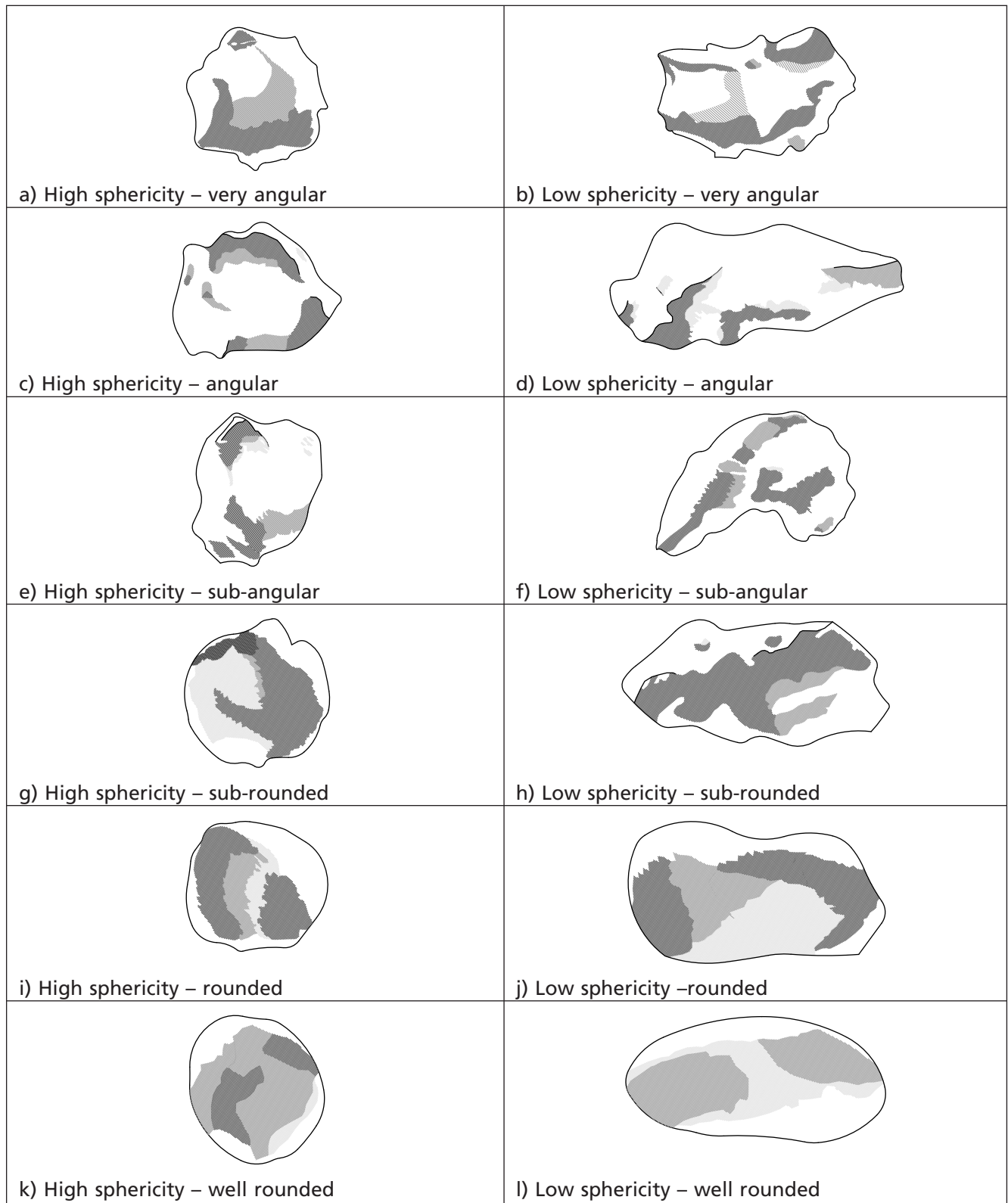
*NOTE 3 The composition of particles visible to the naked eye or with a hand lens may be described. Gravel particles are usually rock fragments, e.g. sandstone, limestone, flint. Sand and finer particles are normally individual mineral grains, e.g. quartz, mica, feldspar.*

*NOTE 4 The composition (mineralogy) of sand is to be reported, such as quartz or shells.*

*NOTE 5 Gravel and sand particles might be coated with mineral matter, including calcite, limonite and other iron oxides as well as black coating of sulfidic minerals. Crystals, for example gypsum in clay, might be present.*

If particles are weathered, showing, for instance, cracking, concentric layering or discoloration, these conditions should be described.

Figure 7 Angularity terms



### 33.4.4 Soil name (Principal soil type and secondary constituents)

#### 33.4.4.1 General

##### COMMENTARY ON 33.4.4.1

The soil name is based on the particle size grading for coarse soils and the plasticity for fine soils. These characteristics are used because they can be measured readily with reasonable precision, and estimated with sufficient accuracy for descriptive purposes. They give a general indication of the probable engineering characteristics of the soil at any particular water content. Figure 6 is a key to the naming and description of soils by hand and eye. Where a soil (omitting any boulders or cobbles) "sticks together when wet and remoulds" it is described as a fine soil ("CLAY" or "SILT" dependent on its plasticity). When it does not stick together and remould, it is described as a coarse soil ("SAND" or "GRAVEL" dependent on its particle size grading). The description of soil containing boulders or cobbles is discussed in 33.4.4.2.

The principal soil type which dominates the engineering behaviour and the secondary constituents which modify that behaviour should be described. The principal soil name should be based on particle size distribution of the coarse fraction and/or the plasticity of the fine fraction as determined by the Atterberg Limits (see Section 8).

The basic soil types and their sub-divisions should be described on the basis of the range of their particle sizes and plasticity as shown in Table 7.

Stratum descriptions presented on exploratory hole and other logs should be reviewed against available laboratory test results, e.g. Atterberg Limits and particle size distributions. Where discrepancies arise due to "miscalibration" of the logger then adjustments should be made; differences due to local material variation or test results for non-representative samples require separate consideration and possible comment on the log or in the report. Consistency descriptions of fine soils should be reviewed against comparable strength results, but generally would not be amended.

*NOTE* The naming of soils falling entirely within sands, gravels, cobbles or boulders is straightforward, as the particles are visible to the naked eye (see 35.2). A common difficulty arises in that the proportions of each soil fraction are percentages by weight, requiring adjustment from the percentage by volume seen by the eye. The naming of soils falling entirely within either clays or silts is less straightforward, relying on simple hand tests (see 35.3). Most natural soils are composed of more than one soil type (see 33.4.4.2 to 33.4.4.5). In composite soil types, cobbles and boulders are treated separately and are discounted in assessing proportions of the other components.

#### 33.4.4.2 Deposits containing boulder-size and cobble-size particles

When the "sample" is considered representative, such as might be the case in very large bulk samples from excavations or in excavated or exposed faces, then these deposits should be described as shown in Table 12.

Table 12 Terms for very coarse soils

|  | Main name | Estimated boulder or cobble content of very coarse fraction |
|--|-----------|---|
| Over 50% of material is very coarse (>63 mm) | BOULDERS  | Over 50% is of boulder size (>200 mm)                       |
|  | COBBLES   | Over 50% is of cobble size (200 mm to 63 mm)                |

The term large boulder does not have an upper size limit, so dimensions should be given wherever available.

Mixtures of very coarse soil particles should be described as in Table 13.

Table 13 **Terms for mixtures of very coarse soils**

| Term                             | Secondary constituent by weight |
|----------------------------------|---------------------------------|
| BOULDERS with occasional cobbles | Up to 5% cobbles                |
| BOULDERS with some cobbles       | 5% to 20% cobbles               |
| BOULDERS with many cobbles       | 20% to 50% cobbles              |
| COBBLES with many boulders       | 20% to 50% boulders             |
| COBBLES with some boulders       | 5% to 20% boulders              |
| COBBLES with occasional boulders | Up to 5% boulders               |

Very coarse soils with secondary finer material (coarse and fine soil) should be described as in Table 14.

Table 14 **Terms for mixtures of very coarse and finer soils**

| Term   | Secondary constituent by weight |
|--|---------------------------------|
| BOULDERS (or COBBLES) with a little finer material | Up to 5% finer material         |
| BOULDERS (or COBBLES) with some finer material     | 5% to 20% finer material        |
| BOULDERS (or COBBLES) with much finer material     | 20% to 50% finer material       |

*NOTE* The description of "finer material" is made in accordance with 33.4.2 to 33.4.6, ignoring the very coarse fraction; the principal soil type name of the finer material can also be given in capital letters, e.g. COBBLES with some sandy CLAY.

Finer material (coarse and fine soil) with a secondary very coarse fraction should be described as in Table 15.

Table 15 **Terms for mixtures of finer and very coarse soils**

| Term   | Secondary constituent by weight |
|--|---------------------------------|
| FINER MATERIAL with low boulder or cobble content    | Up to 5% very coarse particles  |
| FINER MATERIAL with medium boulder or cobble content | 5–20% very coarse particles     |
| FINER MATERIAL with high boulder or cobble content   | >20% very coarse particles      |

*NOTE* The description of "finer material" is made in accordance with 33.4.2 to 33.4.6, ignoring the very coarse fraction.

Percentages are approximate visual estimates in a field description and should only be taken as a subjective guide.



*NOTE* Representative sampling of soil mixtures containing very coarse soils is not possible in normal boreholes, and is very difficult even in conventional trial pits; a representative sample of a soil including boulders would need to weigh more than a tonne (see BS 1377-2); the need for a representative size of sample applies to soil description in the field as much as to laboratory testing. Cobbles or boulders are often noted only in passing on the driller's records, but frequently have a much greater significance to the engineering works (particularly piling or excavation).

The location of individual cobbles and boulders should be noted on the log, even when it is considered appropriate to include the very coarse soil as part of the main description. Where possible, the characteristics of such cobbles and boulders should be described using the terms in Clause 36 and their size in mm can also usefully be reported.

### 33.4.4.3 Deposits containing gravel-size and sand-size particles

#### COMMENTARY ON 33.4.4.3

As noted in 33.4.4.1, a coarse soil (omitting any boulders or cobbles) does not stick together and is described as a "SAND" or "GRAVEL", depending on which of the constituents predominates by weight.

The terms in Table 16 should be used to describe the composition of the coarse fraction; percentages are by weight of the whole material less boulders and cobbles, and are approximate estimates in a field description.

The appropriate adjectives should be used before the principal soil type. Further details should be provided at the end of the main description, after a full stop for clarity, e.g. "Medium dense brown very gravelly coarse SAND. Gravel is subangular fine and medium of sandstone and mudstone".

Table 16 Terms for mixtures of coarse soils

| Term                                | Principal soil type | Approximate proportion of secondary constituent |
|-------------------------------------|---------------------|---|
| Slightly sandy or slightly gravelly | GRAVEL or SAND      | Up to 5%  |
| Sandy or gravelly                   |                     | 5% to 20%                                       |
| Very sandy or gravelly              |                     | Over 20%  |
|                                     | SAND and GRAVEL     | About equal proportions                         |

### 33.4.4.4 Deposits containing silt-size and clay-size particles

#### COMMENTARY ON 33.4.4.4

Most fine soils are mixtures of clay- and silt-size particles; these can include silt-size aggregates of clay minerals and clay-size particles such as quartz. Soils formed solely of coarse silt are not common in nature, although more common as man-made deposits (e.g. tailings, washings and discards).

Fine soil should be described as either a "SILT" or a "CLAY" depending on the plastic properties.

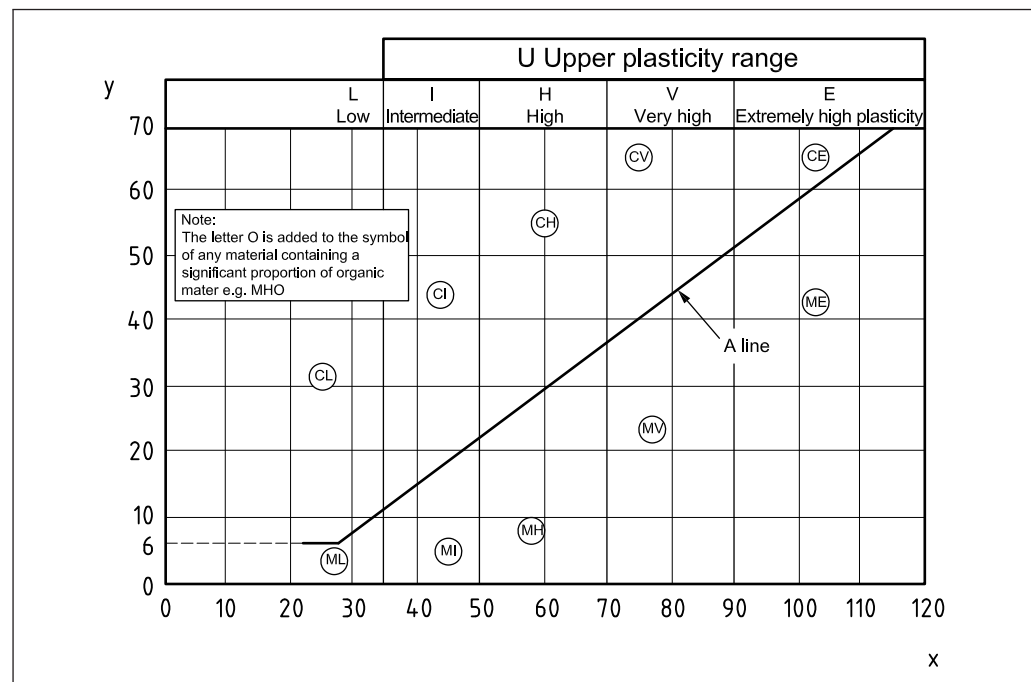
The field distinction between SILT and CLAY should be made using the hand tests in 34.3. The use of secondary fine descriptors in a fine soil is permitted for materials that show behaviour that is borderline between those showing clay-like and silt-like behaviour, hence "silty CLAY" or "clayey SILT", but this should be applied only where the secondary fraction is important, as these terms are qualitative only. Further subdivision such as into slightly clayey or very silty is not appropriate and should not be used.

**NOTE 1** The description of plasticity can be carried out using terms provided in BS EN ISO 14688-1 (low or high plasticity). The definitions provided are based on the plastic limit test, and are thus different from the classification based on the plasticity chart which uses liquid limit (BS EN ISO 14688-2:2004, 4.4). Care and clarity is needed if the descriptive terms are used.

Soils formed solely of coarse silt might not demonstrate plasticity, but should still be described as silt rather than fine sand, if the grains cannot be seen with the naked eye.

**NOTE 2** The distinction between clay and silt is often taken to be the A line on the plasticity chart, with clays plotting above and silts below (see Figure 8) and might not agree with field tests (see Child, 1986 [48] and Smart, 1986 [49]). The effects of clay mineralogy and organic content are significant.

Figure 8 Plasticity chart



#### 33.4.4.5 Deposits containing mixtures of fine soil and coarse soil

The terms in Table 17 should be used to describe those common soils that include a range of soil fractions. The appropriate quantifying terms should be used before the principal soil type. The word order for secondary fractions before the principal soil term should be increasing proportion when there are two coarse soil secondary constituents, or coarse and then fine if one of each. If any of the secondary constituent sizes need qualifying adjectives, these should be added in separate sentences after the main description; this commonly applies to the gravel or, less frequently, the sand fractions. Additional detail should be added in these sentences as appropriate, e.g. "Gravelly very clayey fine to medium SAND with low cobble content. Gravel and cobbles are rounded fine and medium of quartzite". If multiple sentences are used, the proportion of all constituents should be provided in the first sentence.

**NOTE 1** If the secondary fraction is fine, the terms "silt" and "clay" are mutually exclusive and which of the terms silty or clayey is used is based solely on the plastic properties of the fine fraction (see 33.4.4.4), e.g. "gravelly clayey fine SAND". On the other hand, the terms "sandy" and "gravelly" may both be used, in which case the percentages are assessed separately, e.g. "slightly gravelly slightly sandy CLAY." means that the soil contains up to 35% sand and up to 35% gravel. Soils that exhibit cohesion but have a high proportion of coarse particles with the fine soil matrix, such as many glacial deposits, are difficult to describe accurately.

*NOTE 2 Descriptions with cumulative proportions of the various fractions, excluding cobbles and boulders, exceeding 100% are incorrect. However, the sum of the soil fractions in descriptions of soils composed of very coarse particles and finer material could apparently exceed 100%. This is because the description of the finer material and the very coarse soils are apportioned separately.*

Table 17 Terms for mixtures of coarse and fine soils

| Term   | Principal soil type | Approximate proportion of secondary constituent |                         |
|--|---------------------|---|-------------------------|
|  |                     | Coarse soil                                     | Coarse and/or fine soil |
| slightly clayey or slightly silty and/or slightly sandy or slightly gravelly | SAND and/or GRAVEL  | –   | <5%                     |
| clayey or silty and/or sandy or gravelly                                     |                     |   | 5% – 20% <sup>A)</sup>  |
| very clayey or very silty and/or very sandy or very gravelly                 |                     |   | >20% <sup>A)</sup>      |
| very sandy or very gravelly  | SILT <sup>C)</sup>  | >65% <sup>B)</sup>                              | –                       |
| sandy or gravelly  | or                  | 35% – 65%                                       |                         |
| slightly sandy and/or slightly gravelly                                      | CLAY <sup>C)</sup>  | <35%  |                         |

<sup>A)</sup> Or described as fine soil depending on engineering behaviour.

<sup>B)</sup> Or described as coarse soil depending on assessed engineering behaviour.

<sup>C)</sup> Can be silty CLAY or clayey SILT.

### 33.4.4.6 Mineralogy and tertiary constituents

#### COMMENTARY ON 33.4.4.6

*Tertiary constituents are relevant to identifying the geological unit rather than to the engineering properties for example, less than about 10% in a fine soil or 2% in a coarse soil.*

Mineral constituents should be reported before the principal soil type, using qualitative terms such as “slightly micaceous”, “glaucousitic” or “very shelly”. Tertiary constituents should be added at the end of the description using qualitative terms such as “with rare”, “with occasional” or “with frequent”, e.g. “SAND with rare gravel size brick fragments”. These terms are qualitative and no definition of percentage should be given. The terms should be applied consistently on any given job. The size of the tertiary constituents can also be given in mm.

*NOTE Reference samples or photographs can provide a useful record of the proportions of various quantities that the descriptors used imply.*

The description of the carbonate content should be carried out in accordance with BS EN ISO 14688-1. A soil may be described as calcareous if the addition of HCL produces a clear but unsustained effervescence, as slightly calcareous if the efferevescence is weak or sporadic and as highly calcareous if the effervescence is strong and sustained. The description should distinguish whether it is the clasts or the matrix or both that are calcareous. A descriptive term should be used if the presence of carbonate content is detected (i.e. the term carbonate free is not expected on field logs unless as a confirmation that the test has been carried out with a negative result). The acid used in this test should be dilute hydrochloric acid, that is 10% (0.1 M).

### 33.4.5 Anthropogenic ground

#### COMMENTARY ON 33.4.5

*Anthropogenic soils ("made ground" or "fill") have been placed by man and can be divided into those composed of reworked natural soils and those composed of, or containing, man-made materials. A common and useful distinction is that "fill" is placed in a controlled manner, and "made ground" is placed without strict engineering control. Mapping geologists, such as those in the British Geological Survey, might distinguish "made ground" as placed above and "infilled ground" as placed below the original ground surface.*

*The description and testing of natural soils reworked by man is usually straightforward. It might not be possible to carry out significant soil tests on man-made materials, and descriptions are all that remain after the samples have been discarded or pits filled in, making them of great importance.*

Good descriptions should include information on the following aspects, as well as on the soil constituents (this list is not exhaustive):

- a) origin of the material;
- b) presence of large objects such as concrete, masonry, old motor cars, etc.;
- c) presence of voids or collapsible hollow objects;
- d) chemical waste, and dangerous or hazardous substances;
- e) organic matter, with a note on the degree of decomposition;
- f) odours (see Table 18);
- g) striking colour tints;
- h) any dates readable on buried papers, etc.;
- i) signs of heat or combustion underground, e.g. steam emerging from borehole;
- j) structure, variability and any indications of the method of placement;
- k) presence of potentially reactive or expansive materials such as chert or some types of steel making slag (see Table 18); and
- l) any signs of gas such as by odour or bubbling through water.

Some examples of anthropogenic soil descriptions are given in Table 18. These materials are often heterogenous and non-ordered and so a flexible approach to the word order and use of terms can be useful. Photographs of the excavated materials should be taken to support the descriptions given.

Table 18 Some example descriptions of anthropogenic soils

---

"MADE GROUND comprising plastic bags, window frames, garden refuse, newspapers (1964)." "Dense brown sandy GRAVEL with occasional tiles, wire, glass, tyres (MADE GROUND)."

---

"Soft grey sandy CLAY. Rare gravel size brick fragments (MADE GROUND)."

---

"Firm yellow brown slightly sandy CLAY with clods (up to 200 mm) of firm to stiff orange CLAY (EMBANKMENT FILL)."

---

Some types of Made Ground have a wide range of particle types and sizes; it can be very useful to provide approximate proportions of the different materials. For example "Made Ground comprising:

50% pockets up to 1.0 m by 0.4 m of black partially decomposed paper, newspapers (1962), garden refuse and ash;

25% multicoloured (bright colours) clays (possible dyes);

20% concrete slabs up to 1.5 m by 0.2 m lying at 45°;

5% 1 No 200 litre drum slightly corroded, apparently empty, no labels, hydrocarbon odour".

---

"LANDFILL comprising 35% plastic, 20% undecomposed paper, 15% wood (including tree trunk 600 mm diameter), 5% metal (wire and bars up to 15 mm diameter), 5% empty corroded 200 litre drum, 20% matrix of grey clayey GRAVEL of brick and concrete."

---

The description of any odour in the soil should be made wherever possible using the terms in Column 2 of Table 19; these suggestions are not particularly linked to Column 1 but allow more precision than the terms in Column 1 on their own.

The description of odours is not a significant problem area in description; the logger should report any smells noticed using the terms in Table 19 for guidance. If any particularly strong smells are apparent, in an exposure, sample or container, care should be taken to avoid smelling this too closely or deeply and strong odours should not be repeatedly breathed in, in order to make an assessment. Where there is uncertainty in the nature of the odour, "strong odour" should be recorded and the assessment should be based on chemical analysis.

Many materials that emit odours are toxic or carcinogenic and health and safety considerations should override any requirement for noting odours on logs. Where the desk study has indicated that there is a risk from volatile compounds being present in the ground, an appropriate risk assessment should be made prior to carrying out any description. Where odours are unexpectedly encountered during an investigation, work should be temporarily suspended to allow for a reassessment of health and safety requirements so any additional measures can be implemented before work resumes. Where these assessments require respirators to be worn, then this should be indicated on the logs by stating "no odours on logs as description carried out wearing respiratory protective equipment".

|  |
|--|
| <p><b>WARNING.</b> Some persons are allergic/sensitive to traces of some gases and are liable to collapse and require assistance if affected. Although unlikely, the work should be conducted with this possibility in mind. This warning refers to work in the open and should not be confused with the requirements for work in enclosed spaces.</p> |
|--|

Table 19 Terms for description of odours

| Category    | Descriptive terms   |
|-------------|---|
| Camphor     | Bitter<br>Mothballs<br>Acrid  |
| Musk        | Penetrating<br>Pungent  |
| Floral      | Wide range of terms, not likely to be used often in made ground           |
| Peppermint  | Sweet<br>Minty  |
| Ether       | Solvent<br>Acetone<br>Medicinal   |
| Vinegar     | Sharp<br>Acetic<br>Pungent<br>Rancid                                      |
| Putrid      | Rotten egg<br>Rotten cabbage<br>Fishy<br>Disagreeable, sweet<br>Sulfurous |
| Hydrocarbon | Organic<br>Petrol<br>Diesel<br>Oil<br>Asphalt<br>Tar                      |

Particular care should be taken when describing non-natural materials such as slags, clinker and ash. Unless they can be positively identified as such they should be described as, for example, slag-like, or the descriptors “probably” or “possibly” should be used.

*NOTE Slags and similar materials can seldom be positively identified without mineralogical and/or chemical examination. It is often important to identify the exact nature of a slag-like material in view of the fact that steelmaking slags are often volume-unstable, whilst with the exception of a few old blast furnace slags, most blast furnace slags are stable. Similarly, non-ferrous slags might be unstable or liable to high concentrations of toxic elements (see Environment Agency Technical Reports TR P331 [50] and P5-035/TR/01 [51]).*

### 33.4.6 Organic soils

#### COMMENTARY ON 33.4.6

*Soils comprising mainly organic materials are termed peats which accumulate in situ in a mire. They are of low density, typically 1.01 Mg/m<sup>3</sup> to 1.1 Mg/m<sup>3</sup>, which is just over half the density of an inorganic soil. Soils with organic contents up to about 30% by weight and water contents up to about 250% behave largely as inorganic soils, albeit with different parameters (see Hobbs, 1986 [52] and Hobbs, 1987 [53]). Such materials are usually transported and would not be described as peat. This morphological distinction might be difficult to recognize, e.g. within a fluvial sequence, and, therefore, a distinction based on engineering behaviour is to be made.*

Even small quantities of dispersed organic matter within an inorganic soil can have a marked effect on plasticity and hence the engineering properties and produce a distinctive odour and a dark grey, dark brown or dark bluish grey colour; increasing quantities of organic matter heighten these effects (see Hobbs, 1986 [52]). Soils with a high organic content might oxidize and change colour rapidly.

Soils that consist predominantly of plant remains, either fibrous, pseudo-fibrous or amorphous, should be described as peat according to the degree of decomposition and condition as given in Table 20 and Table 21.

*NOTE 1* If the peat forms a horizon of major engineering significance, a fuller description using the schemes of von Post or Troels Smith might be appropriate (see Hobbs, 1986 [52], Hobbs, 1987 [53] and Norbury, 2010 [42]).

*NOTE 2* Dark colours and low densities can be associated with inorganic soils such as volcanic materials or loess.

Table 20 **Types of peats**

|                     |   |
|---------------------|---|
| PEAT                | Accumulates in situ in a mire. Predominantly plant remains, usually dark brown or black, distinctive smell, low bulk density. Can include disseminated or discrete inorganic particles. |
| Fibrous PEAT        | Plant remains clearly recognizable and retain some tensile strength.<br>Water and no solids on squeezing.   |
| Pseudo-fibrous PEAT | Mixture of fibres and amorphous paste.<br>Turbid water and <50% solids on squeezing.  |
| Amorphous PEAT      | No recognizable plant remains, mushy consistency.<br>Paste and >50% solids on squeezing.  |
| HUMUS/<br>TOPSOIL   | Plant remains, living organisms and their excretions together with inorganic constituents.  |

Table 21 **Description of condition of peats**

| Term    | Definition of condition                  |
|---------|--|
| Firm    | Fibres compressed together               |
| Spongy  | Very compressible<br>Open structure      |
| Plastic | Can be moulded in hand<br>Smears fingers |

The organic upper soil layer is usually referred to as "Topsoil" and should be described using a simple scheme (see Norbury, 2010, Chapter 13.1 [42]).

*NOTE 3* Detailed descriptive schemes for Topsoil are available in BS 3882, ISO 25177 and at [www.fao.org/nr/land/soils/soil/EN](http://www.fao.org/nr/land/soils/soil/EN); these are unlikely to be relevant in engineering projects.

Soils that are mixtures of organic and inorganic constituents should be described as indicated in Figure 6. Organic soils containing inorganic matter as a secondary constituent should be described, for example, as slightly clayey or very sandy, these terms being used qualitatively here.

Inorganic soils containing organic matter as a secondary constituent should be described using the qualifying terms in Table 22 (see Swedish Geotechnical Society [54]).

A distinction should be made between the organic and inorganic constituents being disseminated or as discrete inclusions of one within the other.

Table 22 Terms for description of secondary organic matter in an inorganic soil

| Term             | Typical colour | Organic content        | Weight % of dry mass [based on BS EN ISO 14688-2] |
|------------------|----------------|------------------------|---|
| Slightly organic | Grey           | Low organic content    | 2 – 6   |
| Organic          | Dark grey      | Medium organic content | 6 – 30  |
| Very organic     | Black          | High organic content   | >30   |

*NOTE 4* Laboratory determinations of organic content are not essential to the description, but can be used to assist consistency of terminology if required. It is not usual for the classification based on laboratory tests to appear on a field record. The previous comments all refer to recent vegetable matter, not to older materials such as coal or lignite.

It should be taken into account that dark colours and low densities can be associated with inorganic soils such as volcanic materials or loess.

### 33.5 Geological unit, age and type of deposit

The name of the geological unit should be given after the soil description as an indication to the reader of the possible characteristics that the deposit. A guide to naming geological units (*senso lato*) is given on the maps of the British Geological Survey or its antecedents, and it should be written with at least capital initial letters, e.g. London Clay Formation, Bagshot Formation, Lower Lias. Alternatively, the unit should be given in brackets and/or in upper case letters for clarity. The geological unit should be named where this can be done with confidence, but it might not be easy to tell to which unit a sample belongs, or to locate unit boundaries in a borehole or exposure; conjecture should be avoided, but degrees of uncertainty can be indicated.

The most recently published geological map, memoir or sheet explanation should normally be used as a guide and is often adequate and acceptable, but revisions to stratigraphic nomenclature can cause problems when these publications are of different publication dates.

*NOTE 1* The BGS online lexicon provides a useful resource on rock names.<sup>13)</sup>

*NOTE 2* Specialized geological knowledge of a region might be required if a label other than that published is applied, for instance in the recent subdivisions away from Middle or Upper Chalk. On the other hand, broad nomenclature changes can be applied more readily, e.g. Sherwood Sandstone Group for Bunter Sandstone.

The characteristic lithology is sometimes indicated in the formation name, e.g. London Clay Formation, but it should be remembered that at a particular location or horizon the lithology or material type might be completely different from that indicated in the formation name.

*NOTE 3* Formations might be variable in their lithology and knowledge of the formation indicates the possible range of material to be expected. Some indication can be obtained from the key to the one-inch or 1:50 000 and six-inch or 1:10 000, geological maps; from the Sheet Memoir or Sheet Explanation, if published; and from the British Regional Geology Guide (see Annex B).

<sup>13)</sup> See <<http://www.bgs.ac.uk/lexicon>> [last viewed 24 June 2015].



### 33.6 Additional information

Any additional information on the composition, structure, behaviour or other characteristics of the soil that would be of value in assessing its nature and properties should be recorded. A special note should be made if the properties of the material are thought to be unusual in relation to the rest of its description. A note should also be made if there is doubt about whether the description is representative of the ground at the level from which it was sampled.

*NOTE This might be caused, for instance, by the fracture of particles or a loss of fines during sampling, or by the sample size or borehole diameter being too small in relation to the grading or structure of the material being sampled.*

Where relevant, it should be made clear whether the samples on which the description is based were disturbed or undisturbed.

## 34 Field procedures for description of principal inorganic soil type

### COMMENTARY ON CLAUSE 34

*Underlining is recommended in BS EN ISO 14688-1 to identify interlayered soils. This is not recommended for UK use but does not conflict with UK practice.*

### 34.1 Choice of procedure

The simple tests described below should be used for the field assessment and naming of soils, in conjunction with Table 7. The procedures below should not replace laboratory testing, which is necessary to determine relevant properties as and when required; indeed, the results of the testing should be reported together with the original description. Operators should also check their results against laboratory tests to ensure that their judgement is sound.

### 34.2 Field assessment of grading

The distinction between coarse and fine soils should be made on the basis of whether they stick together when wet and remould; the water content might need to be adjusted to correctly assess this.

*NOTE 1 The size of a particle is that of the square sieve aperture through which it would pass.*

*NOTE 2 The coarse silt/fine sand boundary (0.063 mm) can also be assessed by eye, the coarse silt particles only being visible with the aid of a hand lens, and by feel as the silt particles are not gritty.*

*NOTE 3 The boundary between gravels and sands is at 2 mm and so readily visible; the distinction between gravelly and sandy fine soils is also readily made. Particles of 2 mm size are approximately the largest that cling together when moist.*

*NOTE 4 The boundary between silts and clays is made using simple hand tests, see 34.3.*

*NOTE 5 In visually assessing the particle size distribution, an additional judgement is required in order to report the relative proportions by weight rather than by volume; a ratio of 10:7 might be appropriate.*

### 34.3 Field assessment of fine soil

#### 34.3.1 General

##### COMMENTARY ON 34.3.1

*The principal constituents of fine soils are CLAY and SILT. To complete a correct field description of a fine soil it is necessary to distinguish between these two soil types. This can be achieved through a series of hand tests described below.*

To begin the field assessment, a representative sample of the material for examination should be selected and all particles larger than medium sand removed. This soil should be moulded into a ball about 25 mm diameter until it is soft but not sticky, like putty; water should be added or the ball allowed to dry out as necessary in order to achieve the correct consistency.

*NOTE* Water might have to be added to the soil whilst carrying out the following hand tests. Generally, silt soils require more frequent addition of water than clay soils as silts tend to dry faster than clays.

#### 34.3.2 Dilatancy test

- Smooth the soil ball into a pat in the palm of one hand with the thumb, the blade of a knife or a small spatula.
- Shake horizontally, striking the side of the hand vigorously against the other hand several times. Alternatively the pat can be manipulated between the fingers of both hands.
- Squeeze the pat between thumb and fingers.
- Record the speed with which water appears while shaking, and disappears while squeezing as none, slow or rapid.

#### 34.3.3 Toughness test

- Shape the test pat into an elongated pat and roll by hand on a smooth surface or between the palms into a thread about 3 mm in diameter. If the sample is too wet to roll easily, it should be allowed to dry. Fold the sample threads and reroll repeatedly until the thread crumbles at a diameter of about 3 mm when the soil is near the plastic limit. Record the pressure required to roll the thread. Also, record the strength of the thread. After the thread crumbles, the pieces ought to be lumped together and kneaded until the lump crumbles. Record the toughness of the material during this kneading.
- Describe the toughness of the thread and lump as low, medium or high.

#### 34.3.4 Plasticity test

On the basis of observations made during the toughness test, describe the plasticity of the material in accordance with the criteria in Table 23.

Table 23 Terms for description of plasticity

| Description | Criteria   |
|-------------|--|
| Non plastic | A 3 mm thread cannot be rolled at any water content.   |
| Low         | The thread can barely be rolled and the lump cannot be formed when drier than the plastic limit.   |
| Medium      | The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit.                          |
| High        | It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rerolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit. |

#### 34.3.5 Dry strength test

- Remould the soil into several balls with a diameter of about 12 mm and allow them to dry naturally.
- Test the strength of the dry balls or lumps by crushing between the fingers. Note the strength as none, low, medium, high or very high.
- The presence of high-strength water-soluble cementing materials, such as calcium carbonate, might cause high dry strengths. The presence of calcium carbonate can be detected from the intensity of the reaction with dilute hydrochloric acid.

#### 34.3.6 Feel test

- Smear the soil between the fingers or with a blade and note the feel as smooth or silky and whether the surface polishes.

*NOTE The fingertips are remarkably sensitive for this test.*

#### 34.3.7 Test for behaviour in air and water

- Prepare a ball of soil and place it in a bucket or tub of clean water and note the speed with which the ball disintegrates.
- Smear moist soil over a smooth surface (e.g. glass or plastic) or the back of the hand and note the rate of drying and whether the dry soil can be brushed off.

#### 34.3.8 Cohesion test

- Compress the ball or pat between the fingers and note whether it ruptures or deforms.

#### 34.3.9 Selection of principal soil type

The naming of the soil as CLAY or as SILT should be based on the results of these hand tests as in Table 24.

When the various hand tests give conflicting results, one of the hybrid terms "silty CLAY" or "clayey SILT" should be used.

Table 24 Decision on fine soil type from results of hand tests

| Soil description   | CLAY   | Silty CLAY   | Clayey SILT                | SILT                           |
|--------------------|--|--|----------------------------|--------------------------------|
| Dilatancy          | None   | None to slow   | Slow                       | Slow to rapid                  |
| Toughness          | High   | Medium   | Low to medium              | Low or thread cannot be formed |
| Plasticity         | High   | Medium   | Low                        | Non-plastic                    |
| Dry strength       | High to very high  | Medium to high   | Low to medium              | None to low                    |
| Feel               | Smooth, sticky (when wet)  | Smooth   | Silky                      | Silky, gritty                  |
| Behaviour in water | Disintegrates slowly if at all   | Disintegrates slowly   | Disintegrates              | Disintegrates rapidly          |
| Behaviour in air   | Dries slowly with shrinkage  | Dries slowly with shrinkage  | Dries quickly, brushes off | Dries quickly, brushes off     |
| Cohesion           | Deforms without rupture. Maintains shape and moisture during handling. | Deforms without rupture. Maintains shape and moisture during handling. | Moisture drains            | Slumps, moisture drains        |

## 35 Classification of soils

### COMMENTARY ON CLAUSE 35

*A full soil description (in accordance with Clause 33) gives detailed information on the colour, nature (plasticity and particle characteristics) of a soil, as well as on the state (consistency, strength, relative density) and structure (bedding, discontinuities) in which it occurs in a sample, borehole or exposure. Few, if any, soils have identical descriptions. For the purposes of engineering interpretation on a particular project it is often useful to classify the soils on the basis of geological origin of the strata, on some engineering property or properties of the strata, or on any of a large number of combinations of geological and engineering parameters. Such classifications are usually adopted to provide a framework for description and assessment of the ground conditions at a site or series of sites for the particular engineering problem in hand.*

*Probably the most common type of classification, however, places a soil in a limited number of groups with shorthand identifiers on the basis of grading and plasticity of disturbed samples. These characteristics are independent of the particular condition in which a soil occurs, and disregard the influence of the structure, including fabric, of the soil. For this and other reasons, such a classification might appear to differ from the field description of a soil determined in accordance with Clause 33, although it can be useful for those soils to be used as construction materials and is widely used in Europe (see DIN 18196). The more general classification scheme for this purpose, which was devised by the Department of Transport (see Manual of contract documents for highway works [14]), is widely used in the UK. It is recommended that the field descriptions stand as a record of the undisturbed character of the soil. The classification can provide additional useful information as to how the disturbed soil behaves when used as a construction material under various conditions of water content.*

A soil should be classified on the basis of the geological origin or engineering characteristics. This classification is usually based on the results of testing, and so does not appear on borehole or field logs but can be added as an appropriate coding for data transfer.

*NOTE The classification presented in BS EN ISO 14688-2, Annex B is not preferred in UK practice as it takes no account of plasticity or water content.*

## 36 Description and classification of rocks

### 36.1 The scope of rock description

#### COMMENTARY ON 36.1

*As for soils, rock descriptions are made on samples recovered from boreholes and excavations and/or from examination of the in-situ materials. In the following clauses "material characteristics of rocks" refers to those visible in an intact block free from discontinuities, and "mass characteristics of rocks" refers to the overall structure including, particularly, the discontinuities. Thus, only material characteristics can be described on a hand specimen, but an in-situ exposure would permit description of material and mass characteristics. Samples or cores from boreholes normally only allow a limited description of mass characteristics. The quality of the observed sample or exposure is reflected in the level of detail in the description; it is essential that any doubts as to the representativeness or reliability of the sample be stated. An accompanying report gives the origin, type and quality of each sample. In this regard, particularly for rocks, it is often the 5% not recovered that might be more critical than the 95% actually recovered.*

#### 36.1.1 General

The characteristics of a rock of engineering significance should be described; these include the strength, weathering effects and the discontinuities. The discontinuities are the most significant of these (unless the discontinuity spacing is wide with respect to the engineering structure) and so particular attention should be paid to their description.

The geological aspects of a rock should be described using terms from geological science.

*NOTE 1 These (often detailed) considerations of aspects such as mineralogy and petrography are not directly applicable to most engineering problems but the use of particular mineral or rock names can often indicate a range of typical engineering characteristics.*

Geological classification of rock materials should be made to appreciate the geological origin and structure of an area, to establish geological correlation between boreholes, and to distinguish boulders from bedrock.

*NOTE 2 This knowledge of the geology of the rock is also of importance when rock material is required for construction purposes, for example as building stone, concrete aggregate or roadstone.*

*NOTE 3 The characteristics of rock material and rock mass can be inferred from natural outcrops, excavations and rock cores. The amount of information that can be obtained from cores is usually limited, compared to in-situ exposures, unless special techniques are employed.*

#### 36.1.2 Description

Rocks seen in natural outcrops, cores and excavations should be described in the following sequence:

- a) material characteristics (see 36.2):
  - 1) strength;
  - 2) structure;
  - 3) colour;
  - 4) texture;
  - 5) grain size;
  - 6) rock name (in capitals, e.g. "GRANITE");

- b) general information (see 36.3):
  - 1) additional information and minor constituents;
  - 2) geological formation;
- c) mass characteristics (see 36.4):
  - 1) state of weathering;
  - 2) discontinuities;
  - 3) fracture state.

*NOTE* Further information on rock identification is given in BS EN ISO 14689-1.

## 36.2 Description of rock materials

### 36.2.1 Strength of rock material

Strength should be described as follows (see Table 25), in terms related to the rock material's unconfined compressive strength, as recommended in BS EN ISO 14689-1.

Table 25 Terms for description of rock strength

| Term for use in field or based on measurement | Definition for field use   | Definition on basis of Unconfined Compressive Strength measurements<br>MPa |
|---|--|--|
| Extremely weak                                | Can be indented by thumbnail. Gravel sized lumps crush between finger and thumb.   | 0.6 – 1.0  |
| Very weak                                     | Crumbles under firm blows with point of geological hammer. Can be peeled by a pocket knife.                                  | 1 – 5  |
| Weak  | Can be peeled by a pocket knife with difficulty. Shallow indentations made by firm blow with the point of geological hammer. | 5 – 25   |
| Medium strong                                 | Cannot be scraped with pocket knife. Can be fractured with a single firm blow of geological hammer.                          | 25 – 50  |
| Strong  | Requires more than one blow of geological hammer to fracture.  | 50 – 100   |
| Very strong                                   | Requires many blows of geological hammer to fracture.  | 100 – 250  |
| Extremely strong                              | Can only be chipped with geological hammer.  | >250   |

*NOTE* Based on BS EN ISO 14689-1:2003 4.2.7, Table 5.

The strength of a rock material determined in the uniaxial compression is dependent on the water content of the specimen, anisotropy and the test procedure adopted, all of which should be reported. Simple index tests should be used in the field to provide additional data and as a check on the manually assessed strengths.

*NOTE* The point load test (see the ISRM suggested methods [55]) and Schmidt Hammer are amongst the more commonly used field tests. Calibration of the test results with the unconfined compressive strength is required.

Each logger should ensure their descriptions are calibrated by strength determinations as the size and shape of lumps, strength of operator, weight of hammer and surface on which lumps rest affect the field assessment of the strength.

### 36.2.2 Structure

#### COMMENTARY ON 36.2.2

The structure of the rock is concerned with the larger-scale inter-relationship of textural features and lithology. Terms frequently used to describe sedimentary rocks include "bedded", "laminated"; metamorphic rocks can be "foliated", "banded"; igneous rocks can be "flow-banded". Note that structure features are not synonymous with mechanical discontinuities, but they can include potential planes of weakness or incipient discontinuities in the rock mass (see 36.4.3).

Terms to describe the thickness and spacing of these structures are given in Table 26 and should be used where possible.

*NOTE* More detailed terms for the description of structure are provided in BS EN ISO 14689-1:2003, 4.3.2.

Table 26 Terms for description of thickness and spacing of structure

| Thickness term                                | Spacing term    | Thickness or spacing |
|---|-----------------|----------------------|
| Very thickly                                  | Extremely wide  | >6 m                 |
| Very thickly                                  | Very wide       | 2 m – 6 m            |
| Thickly                                       | Wide            | 600 mm – 2 m         |
| Medium  | Medium          | 200 mm – 600 mm      |
| Thinly  | Close           | 60 mm – 200 mm       |
| Very thinly                                   | Very close      | 20 mm – 60 mm        |
| Thickly laminated<br>(Sedimentary)            | Extremely close | 6 mm – 20 mm         |
| Narrowly (Metamorphic<br>and Igneous)         |                 |                      |
| Thinly laminated<br>(Sedimentary)             | Extremely close | <6 mm                |
| Very narrowly<br>(Metamorphic and<br>Igneous) |                 |                      |

*NOTE* A spacing of less than 20 mm or a bed thinner than 6 mm is still large in some deposits. Where finer features are observed, their spacing or thickness can also be given in mm, or additional terms used. For example, a parting is a bed which is only one or two grains thick.

For sedimentary rocks, structures such as bedding may be described as "thick beds" or "thickly bedded", for example, "a thickly bedded SANDSTONE". For igneous and metamorphic rocks, the appropriate descriptive term for the structure should be used, for example, "narrowly foliated GNEISS", "very thinly flow-banded DIORITE".

### 36.2.3 Colour

Rock colours should be described as recommended in BS EN ISO 14689-1 and in Table 7; further comments on the description of colour are given in 33.4.2.

### 36.2.4 Texture

The texture of a rock should be described in accordance with geological terminology.

*NOTE 1 The texture of a rock refers to individual grains and their arrangement, which might show a preferred orientation. Terms frequently used include "porphyritic", "crystalline", "cryptocrystalline", "amorphous" and "glassy". Definitions of such terms are provided in standard geological dictionaries. Geologists often subdivide texture into texture (geometric aspects of particles or crystals) and fabric (arrangement of grains), but this is seldom appropriate in field descriptions for engineering purposes.*

*NOTE 2 Examination of the rock texture might require the use of a hand lens or the microscopic examination of a thin slice of the rock.*

### 36.2.5 Grain size

#### COMMENTARY ON 36.2.5

*Quantified grain size boundaries are only appropriate in sedimentary and derived metamorphic rocks. In other rocks the grain size distinctions are relative. Grain size refers to the average dimension of the minerals or rock fragments dominating the rock's behaviour; this usually means the groundmass, but sometimes separate descriptions of the cement and grains might also be necessary.*

The grain size of the rock material should be described using the scheme in Table 27. The terms "fine", "medium" and "coarse grained" should be applied either to the whole range of grain sizes, e.g. "medium grained limestone", which means it has grains of 0.063 mm to 2 mm, or it can apply to a grain size subdivision, e.g. a "medium grained sandstone", meaning it is made up of grains 0.2 mm to 0.63 mm. Wherever necessary, the terminology used should be reported and explained to avoid any confusion.

Where a rock has bi-modal grain sizes, the grains or clasts and matrix or groundmass should be described separately and linked by quantified terms, as given in Clause 32, together with an indication of whether it is the matrix or groundmass that is likely to affect the engineering behaviour. The size should be estimated by eye, which may be aided by a hand lens in the assessment of fine-grained rocks.

*NOTE The limit of unaided vision is approximately 0.06 mm.*



Table 27 Aid to identification of rocks for engineering purposes (1 of 2)

| Grain size                     |                                   | Bedded rocks (mostly sedimentary)          |                       |   |   |   |  |  |                        |
|--------------------------------|-----------------------------------|--|-----------------------|---|---|---|--|--|------------------------|
| mm                             | Grain size description            |  | CONGLOMERATE          |   | At least 50% of grains are of carbonate |   | At least 50% of grains are of volcanic rock  | SALINE ROCKS   |                        |
|                                | Grain size boundaries approximate | 20 – 6.3                                   | RUDACEOUS             | Rounded boulders cobbles and gravel cemented in a finer matrix  |   | LIMESTONE AND DOLOMITE (undifferentiated) | Calcirudite  | Fragments of volcanic ejecta in a finer matrix. Rounded grains | AGGLOMERATE            |
| 6.3 – 2                        |                                   | Breccia                                    |                       | Angular rock fragments in a finer matrix  | Angular grains                          |   |  |  |                        |
| 2 – 0.63                       |                                   | ARENACEOUS                                 | Coarse                |   |   |   | SANDSTONE Angular or rounded grains commonly cemented by clay, calcitic or iron minerals |  | Calcarenite            |
| 0.63 – 0.2                     |                                   |  | Medium                | Quartzite   |   |   |  |  |                        |
| 0.2 – 0.063                    |                                   |  | Fine                  | Quartz grains and siliceous cement  |   |   |  |  |                        |
| 0.063 – 0.002                  |                                   | ARGILLACEOUS                               |                       |   | Calcareous mudstone                     |   | Cal-cisiltite  | CHALK  | Fine-grained TUFF      |
| <0.002                         |                                   |  | SILTSTONE Mostly silt |   |   |   | Calci-lutite   |  | Very fine-grained TUFF |
| Amorphous or cryptocrystalline |                                   |  |                       | Flint: occurs as bands of nodules in the Chalk<br>Chert: occurs as nodules and beds in limestone and calcareous sandstone |   |   |  | COAL LIGNITE   |                        |
|                                |                                   | Granular cemented – except amorphous rocks |                       |   |   |   |  |  |                        |
|                                |                                   | SILICEOUS                                  |                       | CALCAREOUS  |   | SILICEOUS                                 |  | CARBONACEOUS   |                        |

## SEDIMENTARY ROCKS

Granular cemented rocks vary greatly in strength, some sandstones are stronger than many igneous rocks. Bedding might not show in hand specimens and is best seen in outcrop. Only sedimentary rocks, and some metamorphic rocks derived from them, contain fossils.

Calcareous rocks contain calcite (calcium carbonate) which effervesces with dilute hydrochloric acid.

Table 27 Aid to identification of rocks for engineering purposes (continued) (2 of 2)

| Igneous rocks: generally massive structure and crystalline texture         |                         |   |                              |  | Metamorphic rocks |   |   |
|--|-------------------------|---|------------------------------|--|-------------------|---|---|
| Grain size description   |                         |   |                              |  | Pyroxenite        | Foliated  | Massive   |
| COARSE   | Increasing grain size → | GRANITE <sup>1</sup>  | DIORITE <sup>1,2</sup>       | GABBRO <sup>1,2</sup>                                      | Peridotite        | GNEISS<br>Well-developed but often widely spaced foliation sometimes with schistose bands | MARBLE<br>QUARTZITE<br>GRANULITE<br>HORNFELS<br>AMPHIBOLITE<br>SERPENTINE |
|  |                         | These rocks are sometimes porphyritic and are then described, for example, as porphyritic granite |                              |  |                   | Migmatite<br>Irregularly foliated: mixed schists and gneisses                             |   |
| MEDIUM   |                         | MICRO-GRANITE <sup>1</sup>  | MICRO-DIORITE <sup>1,2</sup> | DOLERITE <sup>3,4</sup>                                    |                   | SCHIST<br>Well-developed undulose foliation: generally much mica                          |   |
| These rocks are sometimes porphyritic and are then described as porphyries |                         |   |                              | PHYLLITE<br>Slightly undulose foliation; sometimes spotted |                   |   |   |
| FINE   |                         | RHYOLITE <sup>4,5</sup>   | ANDESITE <sup>4,5</sup>      | BASALT <sup>5</sup>  |                   | SLATE<br>Well-developed plane cleavage (foliation)  |   |
| Amorphous or crypto-crystalline  |                         | OBSIDIAN <sup>5</sup>   | VOLCANIC GLASS               |  |                   | MYLONITE<br>Found in fault zones, mainly in igneous and metamorphic areas                 |   |
|  |                         | COLOUR  |                              |  |                   | CRYSTALLINE   |   |
|  |                         | Pale  |                              | Dark   |                   |   |   |
|  |                         | ACID<br>Much quartz   | INTERMEDIATE<br>Some quartz  | BASIC<br>Little or no quartz                               | ULTRA BASIC       | SILICEOUS   | Mainly SILICEOUS  |

**IGNEOUS ROCKS**

Composed of closely interlocking mineral grains. Strong when fresh; not porous

Mode of occurrence: 1. Batholiths, 2. Laccoliths, 3. Sills, 4. Dykes, 5. Lava flows, 6. Veins.

**METAMORPHIC ROCKS**

Generally classified according to fabric and mineralogy rather than grain size.

Most metamorphic rocks are distinguished by foliation which might impart fissility. Foliation in gneisses is best observed in outcrop. Non-foliated metamorphics are difficult to recognize except by association.

Most fresh metamorphic rocks are strong although perhaps fissile.

### 36.2.6 Rock name

#### COMMENTARY ON 36.2.6

The rock names given in Table 27 follow general geological practice, but are intended as a guide only; geological training is required for the satisfactory identification of rocks. Engineering properties cannot be inferred directly from the rock names in the table, but the use of a particular name usually indicates a likely range of characteristics to the reader. Combinations of rock names from Table 27 are possible, for instance in the siliceous sedimentary rocks "a sandy MUDSTONE", or combinations of clastic/calcareous/carbonaceous such as "sandy LIMESTONE" or "carbonaceous MUDSTONE".

The rock naming should be based on the scheme in Table 27. Where mineralogies other than those implicit in Table 27 are expected or encountered, the field description might be supplemented by laboratory testing to determine the mineralogy (e.g. elemental chemistry or petrographic examination).

The description of the carbonate content should be carried out in accordance with BS EN ISO 14689-1. A rock should be described as calcareous if the addition of HCl produces a clear but unsustained effervescence, as slightly calcareous if the effervescence is weak or sporadic, and as highly calcareous if the effervescence is strong and sustained. A descriptive term should only be used if the presence of carbonate content is detected.

*NOTE* The term carbonate free is not expected on field logs unless as a confirmation that the test has been carried out with a negative result.

## 36.3 General information

### 36.3.1 Additional information and minor constituents

Any other information or observations on the rock material should be included (mineralogy, other tertiary constituents, presence of large voids) as for soils (see Clause 32). Similar information relating to the rock mass should be included at the end of the description (e.g. face stability, voids). The size, spacing or proportion of any qualitative terms should also be given.

Stability of rock material when it is exposed to a new water or atmospheric environment should be assessed where the relevant conditions might be important (see Table 28) together with a description of the test undertaken. Some weak rocks do not show disintegration in water straight away, but only after being dried.

Table 28 Stability of rock material

| Term          | Changes in free air               | Changes after 24 h in water   | Grade |
|---------------|-----------------------------------|---|-------|
| Stable        | No changes                        | No changes  | 1     |
| Fairly stable | Specimen surface crumbles, slakes | A few fissures are formed, or specimen surface crumbles slightly                          | 2     |
|               |                                   | Many fissures are formed and broken into small lumps, or specimen surface crumbles highly | 3     |
| Unstable      | Specimen disintegrates            | Specimen disintegrates, or nearly the whole specimen surface crumbles                     | 4     |
|               |                                   | The whole specimen becomes muddy, or disintegrates into sand                              | 5     |

### 36.3.2 Geological unit

A guide to the name of a geological unit is given on the maps, memoirs and sheet explanations of the British Geological Survey or its antecedents, and the name should be written with at least capital initial letters, e.g. "Wilmslow Sandstone Formation", "Middle Chalk", "Lower Lias". Alternatively, the unit may be given in brackets and/or in upper case letters for clarity. The geological unit should be named where this can be done with confidence, but it might not be easy to tell to which unit a core or exposure belongs, or to locate unit boundaries in a borehole or exposure; conjecture should be avoided but degrees of uncertainty may be indicated. The logger should make this identification, being best placed while carrying out the logging of the exposure(s), and as a first step to identifying the correct geological code.

*NOTE* The comments in 33.5 are also pertinent in applying unit names to rocks.

## 36.4 Description of rock masses

### 36.4.1 General

The description of rock masses should include information, additional to and following the description of the rock material, about discontinuities and other features of engineering significance. Such additional information should include:

- a) details of the weathering profile;
- b) a full description of the discontinuities or sets of discontinuities;
- c) evaluation of the discontinuity state.

### 36.4.2 Weathering

#### 36.4.2.1 State of weathering

##### *COMMENTARY ON 36.4.2.1*

*The description of the weathering of rocks is of particular importance in ground investigations as most construction on or in a rock mass is undertaken at shallow depth within the zone of surface weathering. Many attempts have been made to devise weathering grade scales for particular rock masses. Scales have been devised for granite (see Moye, 1955 [56]); Southern Province White Chalk subgroup (see Ward, Burland and Gallois [57], CIRIA Project Report 11 [58] and Spink and Norbury, 1990 [59]); mudstones (see Spink and Norbury, 1993 [60]) and Mercia mudstone (see Chandler, 1969 [61]). Working parties of the Engineering Group of the Geological Society have also devised general scales (see Quarterly Journal of Engineering Geology, 1972 [62], Anon, 1995 [63] and Martin and Hencher, 1986 [64]). The relative merits of previous schemes are discussed in Anon, 1995 [63].*

A full factual description should be given of the degree, extent and nature of weathering (Approach 1 as shown in Figure 9) as described in Anon, 1995 [63]. In any rock description, full details of the degree, extent and nature of weathering effects should be included so that readers can appreciate their influence on engineering properties.

*NOTE* Prescriptive classification might be inappropriate in many cases, whereas factual description of weathering:

- is a mandatory part of the full description;
- is of use for subsequent classification;
- is often the only possible way of dealing with weathering where the full profile is not seen;
- is carried out at material and mass scales as appropriate;

- *assists interpretation of how the rock has reached its observed condition; and*
- *provides information for separating rock into zones of similar engineering character.*

Changes in engineering properties caused by weathering should be highlighted. In the event that the cause is uncertain, then terms such as “probably” or “possibly” should be used. In addition to the standard terminology, a typical description should include “non-standard English” descriptors commenting on whether features are due to weathering or not, or which weathering processes or combinations of processes might have resulted in the observed state of the rock. All standard terms should be used according to their defined meanings. To avoid confusion, terms that are used in the prescriptive classifications, such as “slightly”, “highly”, “completely” should not be used in this description. The features most commonly to be examined and reported on should include the following:

- Strength and reduction of strength should be reported using defined terminology. The inclusion of any direct or indirect strength measurements made should be encouraged, whether the test used is “standard” or not. Where it is thought that the change is due to weathering, this information should be provided, for example “very weak within weathered zones”, or “generally strong but weak adjacent to weathered discontinuities” (the extent of any such feature should also be reported as a measurement wherever possible).
- The degree of colour change should be described using terms such as “faintly discoloured”, “discoloured” or “strongly discoloured”. The extent of colour change should be described using terms such as “locally discoloured” or “pervasively discoloured”. These terms are not quantitatively defined for general use, although specific criteria may be applied if appropriate. Additional information should be provided, for example, on the extent of colour change by reporting measurements of inward penetration from discontinuities. Comment should include the nature of the colour changes, and whether they are thought to be as a result of weathering, alteration or some other process. Standard colour charts should be used where appropriate.
- The nature and extent of weathering products should always be described using the appropriate rock or soil descriptive terminology and measurement and should be quantified wherever possible.
- Fracture state and changes should be reported using defined terminology. Actual measurements should be reported because these are more precise, although the terms provide a useful shorthand. Where it is thought that changes are attributable to weathering, this information should be provided, for example, “closely spaced, becoming very closely spaced due to weathering between 15.00 m and 15.75 m”.

#### **36.4.2.2 Weathering classification**

##### **COMMENTARY ON 36.4.2.2**

*The weathering classifications given in BS EN ISO 14689-1 mean that previous Approaches 2 and 3 (see Anon, 1995 [63]) are no longer to be used for geotechnical category 2 projects due to conflict for strict compliance with that standard. However, these approaches might still be appropriate for geotechnical category 3 projects.*

For the classification of weathering in rocks as diverse as, for example, karstic limestones, granites and shales, affected by different weathering processes, a variety of approaches for different situations and scales should be used. Formal classification might often not be appropriate, and should not be used in these cases. Classifications are often useful but should only be applied where well established, where there is sufficient information to classify unambiguously and to do so would be clearly beneficial. Where classification is used, the particular system adopted should be reported.

The approach to description and classification is given in the flow chart in Figure 9 (Anon, 1995 [63], Figure 19); within the various classifications presented as Approaches 4 and 5, definitions of sub-classes in terms of typical characteristics should be broad. Classes may be more rigorously defined by following local experience, site-specific studies or through reference to established schemes. The unit specific weathering classification scheme for the Southern Province White Chalk Subgroup given by *CIRIA Project Report 11* [58] can be used.

In logging cores, the distribution of weathering classes of rock material should be recorded wherever possible (see Martin and Hencher, 1986 [64]).

*NOTE 1 Distribution of weathering classes of the rock mass from which the cores were obtained has to be inferred from the available evidence and this is not always possible. The weathering of a rock mass cannot be deduced from individual boreholes.*

Distribution of weathering classes in a rock mass may be determined by mapping natural and artificial exposures.

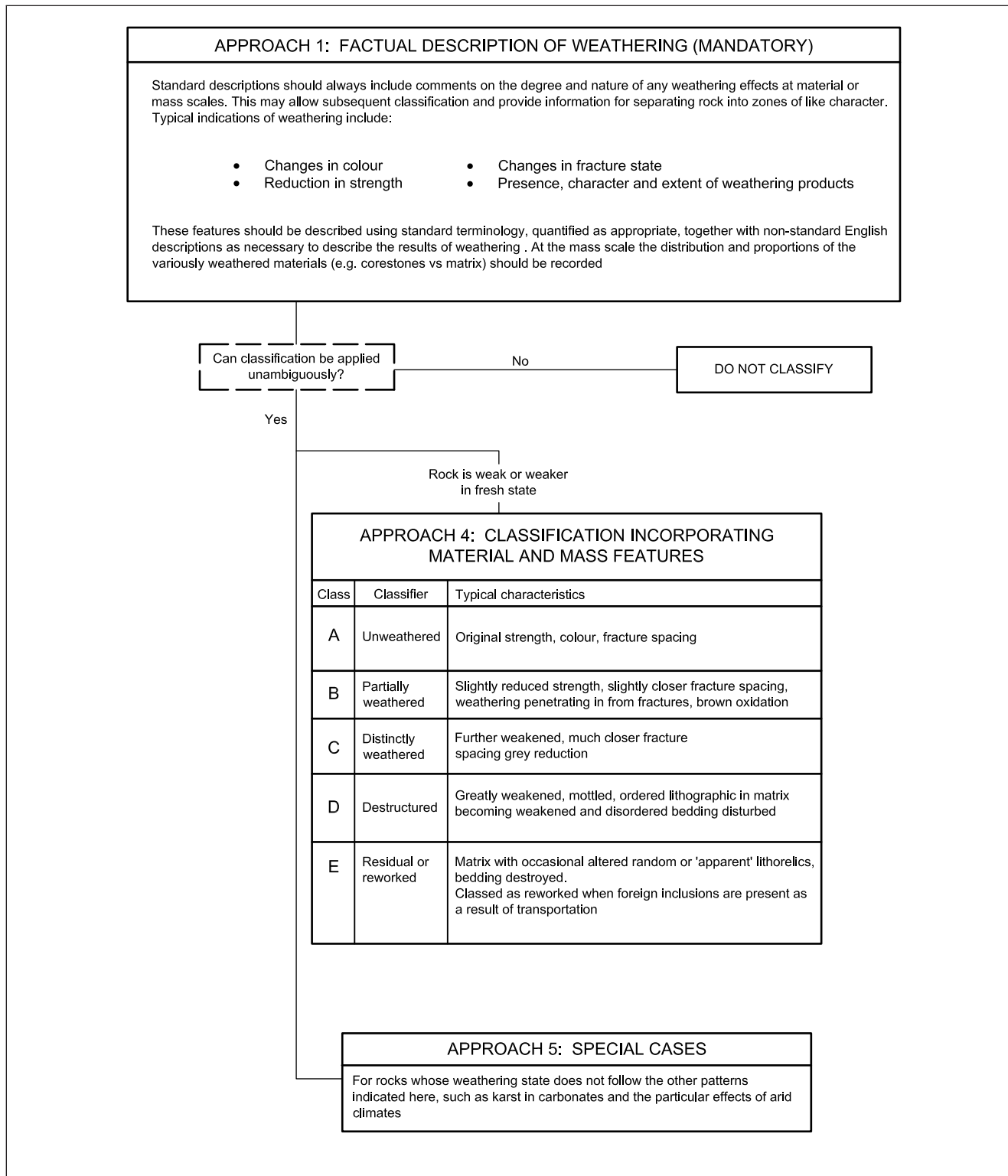
*NOTE 2 Isolated natural exposures of rock and excavations of limited extent are not necessarily representative of the whole rock mass influenced by the project.*

#### **36.4.2.3 State of alteration**

Common terms should be used where appropriate, e.g. kaolinized, mineralized. The terms used for the description of weathering of rock material should be used where appropriate, because in many instances the effects of alteration are not easily distinguished from those brought about by weathering.

*NOTE A full petrographic determination involving microscopic examination of thin slices of the weathered or altered rock may be used to determine the suitability of the rock for particular purposes, for example as a concrete aggregate.*

Figure 9 Description and classification of weathered rock for engineering purposes



### 36.4.3 Discontinuities

#### 36.4.3.1 General

*COMMENTARY ON 36.4.3.1*

*Discontinuities are breaks, fractures or planes of weakness in the rock mass; the discontinuities present in the ground (natural) are the most important, but discontinuities can also be induced by the creation of the exposure. The various types are detailed in Table 29.*

Discontinuities within the rock mass are, in most cases, of primary importance to the rock's overall engineering properties and the maximum possible amount of information from the investigation should be identified and reported as shown in Table 30. A number of different types of discontinuity can be recognized as given in Table 29. Full and accurate description of recovered cores should be carried out and more frequent use should be made of the borehole itself with downhole logging (geophysical, scanning, see Section 5) or cameras. In addition, exposures, whether existing or created for the investigation, should be used wherever practicable to inspect the in-situ mass.

*NOTE 1 A distinction can be drawn between "mechanical discontinuities", which are already open and present in the rock, and "incipient discontinuities", which are inherent potential planes of weakness.*

*NOTE 2 Full recommendations for the recording of discontinuities are given in DIN 4022-1, ISRM, 1978 [65], Quarterly Journal of Engineering Geology, 1977 [66] and ASTM D4879-89. Additional recommendations for describing discontinuities are given in BS EN ISO 14689-1:2003, 4.3.3.*

Free moisture or water flow visible at individual spots or from discontinuities should be described as recommended in BS EN ISO 14689-1:2003.

Table 29 **Types of discontinuity**

| Type of discontinuity | Description   |
|-----------------------|---|
| Joint                 | A discontinuity in the body of rock along which there has been no visible displacement. Joints are synonymous with fissures in soils.   |
| Fault                 | A fracture or fracture zone along which there has been recognizable displacement.   |
| Bedding fracture      | A fracture along the bedding (bedding is a surface parallel to the plane of deposition).  |
| Cleavage fracture     | A fracture along a cleavage (cleavage is a set of parallel planes of weakness often associated with mineral realignment).   |
| Induced fracture      | A discontinuity of non-geological origin, e.g. brought about by coring, blasting, ripping, etc.   |
| Incipient fracture    | A discontinuity which retains some tensile strength, which might not be fully developed or which might be partially cemented. Many incipient fractures are along bedding or cleavage. |

The recording of induced and incipient discontinuities is important as they can indicate weakness within the mass, but they should not be included within the assessment of fracture state, see 36.4.4. If incipient or induced fractures are included in the fracture state, this should be clearly stated on the borehole log.

*NOTE 3 The conventional exclusion of such integral discontinuities from reported indices is conservative, but only for foundation studies; for bulk excavation studies, for instance, it might be preferable to include them.*

*NOTE 4 Discontinuities usually occur in more than one direction in a rock mass, and might be present as distinct sets. Borehole cores provide essentially one dimensional data on discontinuity spacing; exposures or orientated cores are usually needed for full evaluation of the discontinuity pattern.*

The following features of discontinuities should be described (see 36.4.3.2 to 36.4.3.9). The amount of detail included depends on the quality of the exposure or core, whether it is representative and the requirements of the problem in hand. The descriptive terms are summarized in Table 29, which defines the terms in the order in which they should be used in a description.



Table 30 Terminology and checklist for rock discontinuity description

| Orientation  | Discontinuity spacing                                    | Persistence         | Type of termination                   | Roughness                                    | Wall strength     | Aperture                              | Filling   | Seepage   | No. of sets  |
|--|--|---------------------|---------------------------------------|--|-------------------|---------------------------------------|---|---|--|
| Dip amount only in cores                                   |  | Discontinuous       | Cannot normally be described in cores | Intermediate scale (cm) and small scale (mm) | Schmidt hammer    | Cannot normally be described in cores |   | Cannot be described in cores  | Can be summarized in cores where sets of different dip are present             |
|  |  | Stepped             |                                       |  | Point load test   |                                       |   |   |  |
|  |  | Continuous in cores |                                       | Rough  |                   |                                       |   |   |  |
|  | Extremely wide > 6 m                                     |                     | Termination                           | Smooth                                       |                   |                                       | Clean   |   |  |
|  | Very wide 2 m – 6 m                                      |                     |                                       | Striated                                     |                   | Extremely wide > 1 m                  | Surface staining (colour)                               |   |  |
| Take number of readings of dip direction/dip, e.g. 015/18° | Wide 600 mm – 2 m  | Very high > 20 m    |                                       | Undulating                                   |                   | Very wide 0.1 m – 1 m                 |   | Moisture on rock surface  |  |
|  | Medium 200 mm – 600 mm                                   | High 10 m – 20 m    | x (outside exposure)                  | Smooth                                       | Other index tests | Wide 0.01 m – 0.1 m                   | Soil infilling (describe in accordance with Clause 33)  | Dripping water  |  |
|  | Close 60 mm – 200 mm                                     | Medium 3 m – 10 m   | r (within rock)                       | Planar                                       |                   | Moderately wide 2.5 mm – 10 mm        | Mineral coatings (e.g. calcite, chlorite, gypsum, etc.) | Water flow measured per time unit on and individual discontinuity or set of discontinuities |  |
|  | Very close 20 mm – 60 mm                                 | Low 1 m – 3 m       |                                       | Rough  |                   | Open 0.5 mm – 2.5 mm                  |   |   | Record orientation and spacing of individual sets and all details for each set |
|  |  |                     |                                       | Smooth                                       |                   |                                       |   |   |  |
| Report as ranges and on stereo net if appropriate          | Extremely close < 20 mm                                  | Very low < 1 m      | d (against discontinuity)             | Large scale (m)                              |                   | Partly open 0.25 mm – 0.5 mm          | Other (specify)   | Small flow 0.5 l/s – 5.0 l/s  |  |
|  | Take number of readings and state min., average and max. |                     | Record also size of discontinuity     | Waviness                                     | Visual assessment | Tight 0.1 mm – 0.25 mm                | Record width and continuity of infill                   | Medium flow 0.05 l/s – 0.5 l/s  |  |
|  |  |                     |                                       | Curvature                                    |                   | Very tight < 0.1 mm                   |   | Large flow > 5 l/s  |  |
|  |  |                     |                                       | Straightness                                 |                   |                                       |   |   |  |
|  |  |                     |                                       | Measure amplitude and wavelength of feature  |                   |                                       |   |   |  |

### 36.4.3.2 Orientation

The convention of three-digit dip direction/two-digit dip should be used, e.g. 015°/26°. In cores, only dip related to the normal to the core axis should normally be determined unless core orientation or downhole measurement methods have been used.

### 36.4.3.3 Spacing

The descriptive terms in Table 29 should be used for discontinuity spacing in one dimension. The spacing should be measured for each joint set; the convention is to measure discontinuity spacings perpendicular to the discontinuities. In cores with steeply dipping discontinuities, it might only be possible to measure "spacing" along the core axis; if so, this should be stated.

*NOTE The spacing of discontinuities in three dimensions may be described with reference to the size and shape of rock blocks bounded by discontinuities using the terms defined in BS EN ISO 14689-1. The use of these terms requires an understanding of the distribution of discontinuities in three dimensions, and so cannot be used in description of drill core. Where there is sufficient exposure for such terms to be used, the measurement of discontinuity spacings along orthogonal scan lines might be more appropriate.*

### 36.4.3.4 Persistence

The descriptive terminology should be applied to sets; actual measurements are preferred for individual discontinuities. Very limited information is available from cores.

### 36.4.3.5 Termination

The nature of the discontinuity termination should be recorded in the context of the size of the exposure. A discontinuity might start and end within or beyond the limits of the exposure. Very limited information is available from cores.

### 36.4.3.6 Roughness

Descriptions should be made at three scales, where possible (see DIN 4022-1). The intermediate scale (several cm) should be divided into stepped, undulating or planar. The small scale (several mm) of rough, smooth or striated should be superimposed on the intermediate scale. Smooth surfaces can be matt or polished; the degree of polish should be qualitatively described. The term striated should only be used where there is clear evidence of shear displacement. There might also be a large scale (several m) which may be reported as measured wavelength and amplitude; the smaller scales may be reported similarly. An individual joint can, therefore, be described as wavy (wavelength 2 m, amplitude 1 m), stepped (wavelength 500 mm, amplitude 200 mm) and smooth. If more precise detail is required, roughness should be measured quantitatively (see DIN 4022-1).

### 36.4.3.7 Wall strength

Index tests should be used to measure wall strength. Numerical results should be reported, and can be summarized using the terms in 36.2.1.

Wall weathering and alteration should be described in accordance with 36.4.2.

### 36.4.3.8 Aperture and infilling

Where possible, measurements of aperture should be reported. Full description of rock, soil or mineral infill should be provided. Care should be taken when reporting aperture in rock cores; the observer should comment on whether the reported apertures are present in the intact rock mass, or a consequence of geomorphological/weathering agencies, or whether due to engineering activities or creation of the exposure. The thickness and type of infill should be reported using standard terms, e.g. 1 mm surface film of calcite, 10 mm cemented breccia.

### 36.4.3.9 Number of sets

The descriptive terminology may be applied to individual discontinuities, or summarized to sets or to zones of uniform character.

Where extensive detail of the rock mass is required, systematic record sheets should be used and numerical data for use in rock mass rating schemes should be recorded to facilitate data handling, see for example IRSM, 1978 [65].

## 36.4.4 Discontinuity state

### COMMENTARY ON 36.4.4

*Various criteria can be used for quantitative description of the fracture state of rock cores; these are the total core recovery (TCR), solid core recovery (SCR), fracture index and rock quality designation (RQD). The definitions of these terms are given in BS EN ISO 22475-1. The fundamental definition is that solid core has a full diameter, uninterrupted by natural discontinuities, but not necessarily a full circumference and is commonly measured along the core axis or other scan line (see DIN 4022-1 and Laubscher, 1990 [67]). By this definition, core is solid unless intersected by more than one joint set with different strike directions.*

The measurement of the discontinuity state should be made using the indices defined in Table 31. The measurement of discontinuity state of rotary cores and in-situ exposures should follow the general procedures in this clause; RQD and fracture index can be determined from scanlines where appropriate.

Table 31 Terms for classification of discontinuity state (see Figure 10)

|                |   |
|----------------|---|
| TCR (%)        | Length of core recovered (solid and non-intact) expressed as a ratio of the length of core run.   |
| SCR (%)        | Length of solid core recovered expressed as a ratio of the length of core run. Solid core has a full diameter, uninterrupted by natural discontinuities, but not necessarily a full circumference and is commonly measured along the core axis or other scan line.  |
| RQD (%)        | Length of solid core each pieces longer than 100 mm expressed as a ratio of the length of core run.   |
| Fracture index | Count of the number or spacing of fractures over an arbitrary length of core of similar intensity of fracturing recorded as minimum/mode/maximum. Commonly reported as Fracture Spacing (If, mm) or as Fracture Index (FI, number of fractures per metre). Where core is non-intact in the ground, the abbreviation NI may be used. |

*NOTE The total core recovery (TCR) records the proportion of core recovered and is read with the description, solid core recovery (SCR) and rock quality designation (RQD). The TCR of itself gives little information on the character of the core or the rock from which it was recovered. This measurement is required to ensure that all depth related records such as boundaries, markers and samples are correct.*

Where a section of core contains no fractures, between two sections of fractured core, a single fracture spacing (If) equal to the length of non-fractured core should be reported. Non-intact zones of about 300 mm or greater extent can usefully be identified as a separate unit within the discontinuity log to enable their ready identification in a borehole record.

Where core loss is identified, the logger (in consultation with the driller) should identify the amount of loss and, wherever practicable, the depth at which it occurs. There are practical difficulties in recording the TCR whenever the recovery is not 100% (Valentine and Norbury, 2011 [68]), which occurs where:

- the core recovery is less than complete as core has been lost; or
- there is more recovery than there should be with core being gained; this can either result from core being lost from one core run and recovered in the subsequent run, or from core swelling after recovery.

*NOTE 1* Assignment of a depth range to all zones of core loss enables corrections to be made to the actual depths of the recovered core and thus the true depth of any logging observations and sub-samples taken.

*NOTE 2* Apparent core gains can occur where core is dropped from one run by being left down the hole but picked up on the subsequent core run. This gives core recovery of less than 100% in the first run, but might well result in measurements of recovery ostensibly exceeding 100% in the subsequent run or runs.

The logger should correct the recorded depths to take account of core losses and gains, which might extend over several core runs, preferably before recording any depth related remarks and test and sample depths.

*NOTE 3* The application of these terms is illustrated in Figure 10 (see Bienawski, 1984 [69]).

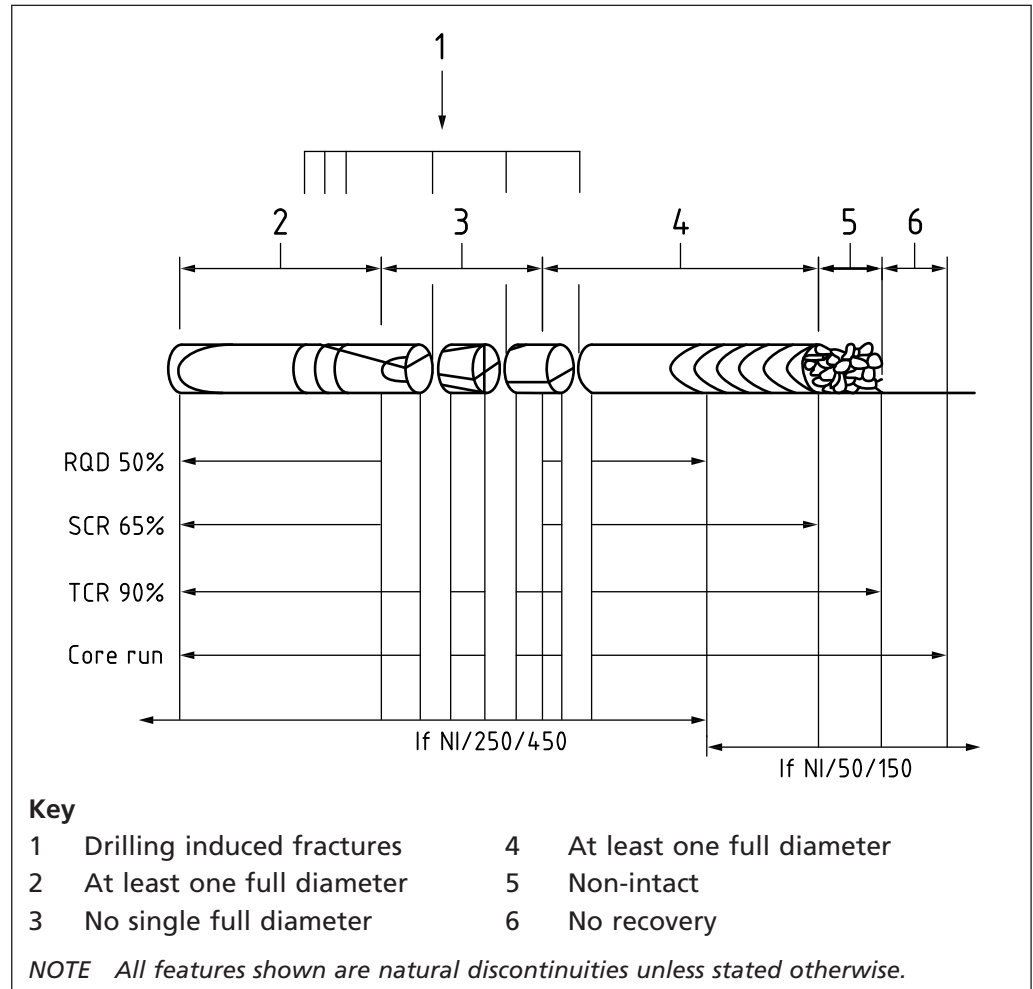
It is conventional to include only natural fractures in determining these indices; departure from this convention should be stated on the log, as should any uncertainties. The treatment of incipient discontinuities should be reported.

*NOTE 4* Useful guidance on the interpretation of natural and induced fractures is provided in Deere and Deere, 1988 [70] and Kulander et al., 1990 [71]).

*NOTE 5* It is not usually appropriate to record these indices, other than TCR, in soils or other materials, such as concrete or brickwork, recovered by rotary core drilling.

Alternative definitions or applications of these indices, and particularly of RQD, have been put forward widely in the literature; if any alternative definitions are used this should be indicated on the borehole or exposure log.

Figure 10 Application of fracture state terms for rock cores



### 36.4.5 Example rock material and rock mass descriptions

The overall description should match the style and coverage as appropriate of the examples of rock descriptions given in Table 32.

Table 32 Example rock descriptions

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An example of a description of a rock mass seen in a section of drill core might be "Very strong thinly flow banded dark greyish green fine-grained quartz DOLERITE. Joints dipping 5 degrees very widely spaced with red penetrative staining to 10 mm and locally weathered to moderately strong to 5 mm penetration". The borehole log also includes the indices giving the fracture state.

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An example of the description of a rock mass seen in a trial pit might be "Very stiff fissured thickly laminated to very thinly bedded brown mottled grey CLAY varying to very weak grey mottled brown MUDSTONE. Occasional gypsum crystals up to 5 mm, and rare pyritized wood fragments. Fissures very closely spaced (20 mm to 40 mm) with brown oxidation penetrating up to 3 mm. (Class B London Clay Formation)".

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An example of the description of a rock mass seen in a quarry face might be "Medium strong very thinly bedded reddish brown fine and medium grained SANDSTONE. Rare moderately weak light green siltstone elliptical inclusions up to 20 mm by 5 mm. (Weathered Sherwood Sandstone Group). Small blocky jointing. Joint set 1 – 045/75, medium spaced, medium persistence, terminations outside exposure, curved planar rough, weak friable up to 5 mm penetration moderately wide open, clean. Joint set 2 – 110–130/80–90, closely spaced, low persistence, terminations outside exposure and against discontinuity, planar smooth weak friable up to 3 mm penetration, tight, clean. Bedding fracture set 3 – 180–190/0–10, medium spaced, high persistence, no termination seen, straight stepped smooth, slightly polished, moderately open up to 1 mm infilled with firm grey clay. Joints generally dry, local small flows". If this is from a cored borehole, the log should also include the indices giving the fracture state; comparable information can also be obtained from scanlines on an exposure.

Such a description could refer to the rock mass in a specified location in a quarry. An account of the whole quarry would require many such descriptions perhaps displayed on engineering geological maps, plans and sections. Data on the orientation of discontinuities can be displayed and analysed using stereonet (see Norbury, Child and Spink, 1986 [72]) or rosette diagrams.

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*NOTE In addition to classification on a geological basis, the assessment of rock mass conditions can be summarized and assessed for engineering purposes using one of the many available rating systems. By ascribing weighted scores to certain pertinent characteristics of the rock mass, a classification or zonation of the rock in the area influenced by the engineering works can be derived. A useful summary of these ratings is given in Bienawski, 1989 [73].*

## Section 7: Field tests

### 37 General

#### COMMENTARY ON CLAUSE 37

See Section 3 for detailed recommendations on the planning of ground investigations, where it is recommended that all ground investigations consist of both field and laboratory investigations.

Utilities should be identified before any intrusive work commences (see 19.2.4).

Appropriate field tests should be selected, taking into account the information and parameters that are required for the geotechnical design. This section covers both in-situ field tests used as part of the ground investigation process and also large scale field tests or trials targeted at specific specialist requirements. For the former application, Table 33 (based on Lunne et al., 1997 [74]) and BS EN 1997-2:2007, Table 2.1 should be used along with any other available tables to aid the selection of tests based on their applicability, given the ground conditions likely to be encountered and the parameters to be established.

Field tests should be used at all stages of ground investigations (for example, to assist in the siting of boreholes, trial pits, etc.).

The larger scale field tests should be used where the mass characteristics of the ground might differ appreciably from the material characteristics determined by laboratory testing (but they can also be used to validate design procedures).

*NOTE 1* These differences normally arise from several factors, the most important of which are the extent to which the laboratory samples are representative of the mass and the quality of sample that can be obtained for laboratory testing. Factors affecting sample quality are considered in Clause 25 and attention is drawn to factors affecting the representative nature of a laboratory sample. These factors are partly related to the in-situ conditions of stress, pore pressure and degree of saturation, and can be altered from an unknown in-situ state by the sampling processes. Consequently, their influence cannot be accounted for in laboratory testing.

The material tested in situ by a field test is analogous to a laboratory sample, and should be deemed to be an "in-situ sample".

*NOTE 2* The in-situ conditions of the sample can be affected by the process of gaining access to the position, e.g. drilling a borehole, digging a trial pit or pushing a probe, but for large scale tests the effect is usually very much less than for a laboratory sample and even for smaller scale tests, e.g. probing tests, any disturbance is likely to be localized and repeatable.

The controlling effects of the nature, orientation, persistence and spacing of discontinuities (see Anon, 1972 [75]), the nature of any filling and the size of sample required for it to be representative should all be taken into account. The selection and preparation of samples in the field should be subjected to the same requirements as for laboratory samples to ensure that they are representative. Considerable attention should be given in the field to these aspects, because normally fewer large scale field tests can be carried out than laboratory tests and it might not be possible to visually examine the in-situ sample.

*NOTE 3* The scale of sample to be tested in a field test depends on the nature of the ground and type of test, and might vary from a fraction of a metre, such as in-situ triaxial state or stress measurements, to several metres for field trials, to one or two kilometres in a pumping test.

Table 33 The applicability and usefulness of in-situ tests

| Group                            | Device                             | Soil parameters |          |                  |                      |       |                  |       |                  |                  |       | Ground type       |                  |                             |           |           |        |      |      |      |      |   |
|----------------------------------|------------------------------------|-----------------|----------|------------------|----------------------|-------|------------------|-------|------------------|------------------|-------|-------------------|------------------|-----------------------------|-----------|-----------|--------|------|------|------|------|---|
|                                  |                                    | Soil type       | Pro-file | $u$              | $\varphi^{(\wedge)}$ | $s_u$ | $I_b$            | $M_v$ | $c_v$            | $k$              | $G_o$ | $\sigma_h$        | OCR              | $\sigma\text{-}\varepsilon$ | Hard rock | Soft rock | Gravel | Sand | Silt | Clay | Peat |   |
| Pen-etrom-eters                  | Dynamic probing                    | C               | B        | -                | C                    | C     | C                | -     | -                | C                | -     | -                 | C                | -                           | -         | C         | B      | A    | B    | B    | B    |   |
|                                  | Mechanical (CPTM)                  | B               | A/B      | -                | C                    | B     | C                | -     | -                | C                | C     | C                 | -                | -                           | -         | C         | C      | A    | A    | A    | A    |   |
|                                  | Electric (CPT)                     | B               | A        | -                | C                    | B     | A/B              | C     | -                | B                | B/C   | B                 | -                | -                           | -         | C         | C      | A    | A    | A    | A    |   |
|                                  | Piezocene (CPTU)                   | A               | A        | A                | B                    | B     | A/B              | B     | B                | B                | B/C   | B                 | C                | -                           | -         | C         | C      | A    | A    | A    | A    |   |
|                                  | Seismic (SCPT/SCPTU)               | A               | A        | A                | B                    | A/B   | A/B              | B     | A/B              | B                | A     | B                 | B                | B                           | -         | C         | C      | A    | A    | A    | A    |   |
|                                  | Flat dilatometer (DMT)             | B               | A        | C                | B                    | B     | C                | B     | -                | B                | B     | B                 | C                | -                           | -         | C         | C      | A    | A    | A    | A    |   |
| Standard penetra-tion test (SPT) | Standard penetra-tion test (SPT)   | A               | B        | -                | C                    | B     | -                | -     | C                | -                | C     | -                 | -                | -                           | -         | C         | B      | A    | B    | A    | B    |   |
|                                  | Resistivity probe                  | B               | B        | -                | B                    | C     | A                | C     | -                | -                | -     | -                 | -                | -                           | -         | C         | -      | A    | A    | A    | A    |   |
| Pres-surem-eters                 | Pre-bored (PBP)                    | B               | B        | -                | C                    | B     | C                | B     | C                | -                | B     | C                 | C                | C                           | -         | A         | B      | B    | B    | A    | B    |   |
|                                  | Self boring (SBP)                  | B               | B        | A <sup>(B)</sup> | B                    | B     | A <sup>(B)</sup> | B     | A <sup>(C)</sup> | A/B              | B     | A/ <sup>(B)</sup> | B <sup>(C)</sup> | -                           | -         | B         | -      | B    | B    | A    | B    |   |
|                                  | Full displace-ment (FDP)           | B               | B        | -                | C                    | B     | C                | C     | -                | A <sup>(C)</sup> | C     | C                 | C                | -                           | -         | C         | -      | B    | B    | A    | A    |   |
| Others                           | Vane                               | B               | C        | -                | -                    | A     | -                | -     | -                | -                | -     | -                 | B/C              | B                           | -         | -         | -      | -    | -    | A    | B    |   |
|                                  | Plate load                         | C               | -        | -                | C                    | B     | B                | C     | C                | A                | C     | B                 | B                | -                           | -         | A         | B      | B    | A    | A    | A    |   |
|                                  | Screw plate                        | C               | C        | -                | C                    | B     | B                | C     | C                | A                | C     | B                 | -                | -                           | -         | C         | -      | A    | A    | A    | A    |   |
|                                  | Borehole permeability              | C               | -        | A                | -                    | -     | -                | B     | A                | -                | -     | -                 | -                | -                           | -         | A         | A      | A    | A    | A    | B    |   |
|                                  | Hydraulic fracture                 | -               | -        | B                | -                    | -     | -                | C     | C                | -                | B     | -                 | -                | -                           | -         | B         | B      | -    | -    | C    | A    | C |
|                                  | Crosshole/downhole/surface seismic | C               | C        | -                | -                    | -     | -                | -     | -                | A                | -     | B                 | -                | -                           | -         | A         | A      | A    | A    | A    | A    |   |

Applicability: A = high / B = moderate / C = low / - = none

Soil parameter definitions:  $u$  = in situ static pore pressure /  $\varphi'$  = effective internal friction angle /  $s_u$  = undrained shear strength /  $I_b$  = density index /  $M_v$  = constrained modulus /  $c_v$  = coefficient of consolidation /  $k$  = coefficient of permeability /  $G_o$  = shear modulus at small strains /  $\sigma_h$  = horizontal stress / OCR = overconsolidation ratio /  $\sigma\text{-}\varepsilon$  = stress-strain relationship

<sup>A)</sup> Depends on soil type. / <sup>B)</sup> Only when pore pressure sensor fitted. / <sup>C)</sup> Only when displacement sensor fitted.



Field/in-situ tests should be used as part of all investigations but are particularly valuable where the preparation of representative laboratory samples is complicated by one or more of the following conditions.

- a) The spacing of the bedding, fabric and discontinuity features in the mass is such that a sample representing the mass would be too large for laboratory test equipment. The discontinuities are assumed to govern the geomechanical response of the material on the scale of the structure concerned.
- b) It is difficult to obtain samples of adequate quality because of the lack of cohesion or irreversible changes in mechanical properties; these result from changes in the pore pressure, the degree of saturation and stress environments during sampling, and from physical disturbance resulting from the sampling procedure.
- c) It is difficult to determine the in-situ conditions, such as pore water pressure, degree of saturation and stress environments for reproduction in the laboratory testing.
- d) Sample disturbance due to delays and transportation from remote sites is excessive.
- e) The zone of interest might be inaccessible to sampling equipment.

The larger scale field tests are expensive and should not be undertaken before obtaining a comprehensive understanding of the geology and nature of the ground.

*NOTE 4 Standards are now generally available for the more common in-situ ground investigation tests but the more specialist and large scale tests are generally designed to take account of the nature of the works and the character of the ground based on the findings of the initial ground investigation. Careful observation is required in all field tests. Continuous recording equipment can be used to improve the precision, e.g. to note small changes during the test, and can increase the quality of the data obtained.*

## 38 Probing

### COMMENTARY ON CLAUSE 38

*Probing from the surface probably represents the oldest method of investigating the depth to a hard stratum where the overburden is of low strength and not unduly thick. The simplest probe is a sharpened steel rod, which is pushed or driven into the soil until it meets resistance. The method is still of use where it is likely that there are relatively thin layers of low strength soils overlying much higher strength soils, when the thickness of the soft stratum might be determined over a wide area very quickly and economically. The method has many limitations, and a variety of more sophisticated methods have been developed in an attempt to overcome these and to extend the use beyond that of detecting a bearing stratum within the soils present.*

## 38.1 Dynamic probing

### COMMENTARY ON 38.1

*The apparatus for dynamic probing comprises a sectional rod with a cone fitted at the base of a slightly greater diameter than the rod. It is driven into the ground by a constant mass that is allowed to fall on the rod through a constant distance, and arranged such that the mass falls through the constant distance without the operator having to use their judgement in any way. This is usually achieved using a mechanical latch on machine-driven equipment and mechanical indication on hand-operated apparatus. The number of blows to drive the tip a given distance is recorded as the blow count. The process is repeated throughout a profile. Dynamic probing using small track mounted machines (generally used also for dynamic sampling) and hand-operated equipment, provides an indication of stratigraphy and ground strength.*

*Interpolation of data between boreholes using site specific correlations with known ground property data might be possible. Where a ground investigation has been carried out by exploratory holes, it might be possible to use dynamic probing to check rapidly and cheaply that conditions on neighbouring positions are similar. As with other types of penetrometer, probing can give unreliable results in soils containing cobbles or boulders, which can easily be mistaken for bedrock. The main limitation of dynamic probing is that the soil being tested cannot be identified, although sampling techniques using the machine operated equipment have been developed. Some examples of the use and interpretation of dynamic probing results are given in BS EN 1997-2:2007, particularly Annex G, and NA to BS EN 1997-2, but these correlations have not all been proven in UK conditions.*

The selection of the type of dynamic probe apparatus to be used and the method of working should be carried out in accordance with BS EN ISO 22476-2, BS EN 1997-2 and NA to BS EN 1997-2. The basis for the selection of which type is to be used should be that the driving energy (hammer mass and height of fall) is appropriate for the ground conditions anticipated.

There have been changes to some of the configurations commonly used in the UK and care should be taken to ensure that the correct name is assigned to the configuration being used.

The results of dynamic probing may be correlated with the results of other types of field test and/or used to estimate various soil parameters. Some correlations are given in BS EN 1997-2; these are subject to the caveats in NA to BS EN 1997-2. Where these and other published correlations are used, care should be taken to ensure that they are applicable for the driving energy of the dynamic probing apparatus used.

*NOTE The fact that the rod is slightly smaller in diameter than the base of the cone to some extent prevents shaft friction influencing the results. In some soils where the hole closes in on the rods this factor is to be taken into account. One method is to correlate the torque measurements, which have been taken as part of the test before each new extension rod is added, with the blow count and subtract this from the measured blow count (see Butcher, McElmeel and Powell, 1995 [76]). Shaft friction can be eliminated or substantially reduced by boring a hole to the depth required for each test, or by providing the exterior of the rods with either a sleeve or a lubricating mud injected behind the cone. The size of the cone, mass of hammer and the distance through which the constant mass is allowed to fall have only recently been standardized in the UK, so there is only limited practical experience behind the test, although some published data are available linking the results of certain tests with soil parameters determined by other methods (see Butcher, McElmeel and Powell, 1995 [76]). Cone size and hammer weight are available in different configurations so as to ensure various ground types can be penetrated and measureable results obtained (see BS EN ISO 22476-2).*

Other “non-standardized” dynamic probing devices exist and may be used, where appropriate; the most commonly used in the UK is the Mackintosh Probe (see Clayton et al., 1995 [22]); with this device the hammer is lifted by hand and the driving energy sometimes declines due to operator fatigue. Care should be taken when these devices are used for anything other than generalized profiling.

## 38.2 Dynamic cone penetrometer

### COMMENTARY ON 38.2

*The dynamic cone penetrometer (DCP) is a type of dynamic probe intended, primarily, to obtain values of California Bearing Ratio by correlation. There is no formal standard for this test but it is described in Design manual for roads and bridges, Vol 7 [77]. The DCP results are presented as penetration/blow, i.e. the inverse of general practice for dynamic probing in 38.1. A summary of the history of its development and a review of the published correlations is given in Booth, Keeton and Gosling, 2008 [78].*

In the absence of a standard, the test should be carried out and the data processed following the guidance given by the Highways Agency or in the manufacturer’s literature. The correlation adopted should be appropriate to the cone used for the test but even so the results should be treated with caution.

## 39 Static cone penetration testing

### 39.1 General

#### COMMENTARY ON 39.1

*This is probably the most widely used in-situ test worldwide and has an extensive database of published correlations for geotechnical parameters. The cone penetration test (CPT) consists of “pushing” a conical 60° cone into the ground at a constant rate and recording the pushing force required to do this. The cone penetration test was originally developed in the 1930s for use in recent alluvial soils. Its application, however, has since been widened to other materials, such as dense sands, stiff and very stiff clays, gravelly clays, chalk, other weaker rocks and many more (see Lunne et al., 1997 [74]). However, penetration is usually terminated when dense gravel, coarse gravel, a cobble or rock is encountered. The depth of penetration is limited by both the safe load that can be carried by the cone, and the push system together with the reaction force available for pushing the penetrometer into the ground. The latter is controlled by the capacity of the hydraulic equipment and the weight of CPT machine, or capacity of any anchorage included. CPT termination at depth above the scheduled depth (i.e. refusal) is likely to occur where the operator judges that excessive bending of the cone or section of the push rod string is taking place, largely based on information from the inbuilt inclinometer.*

*The most common forms of cone penetration test uses “electrical sensors with the cone” to measure the load on the cone; these are referred to as electrical CPT.*

*A build-up of skin friction along the rods, together with the load on the cone, can prevent further penetration, because the total thrust capacity of the machine is reached. The friction on the sounding tubes can be reduced by the use of a friction reducer. Where a penetration test is stopped for any of the above reasons, it might be possible to prebore and continue the test from the bottom of the prebored hole. If this procedure is adopted, it is necessary to provide lateral support to rods in the prebored hole. For softer strata over harder strata the CPT rig can install casing to support the cone rods through the soft strata, allowing penetration of the harder strata. It is important to use appropriate resolution and accuracy (see BS EN ISO 22476-1) together with all required corrections, e.g. for end area effects (for example, for very soft clays and silts, more sensitive cones could be used).*

*There have been extensive developments in the technology of the static cone penetration test with probes to measure a variety of other parameters such as electrical conductivity, temperature and the velocity of seismic waves (see Lunne et al., 1997 [74]). Probes and equipment for use on the seabed in water depths of up to 5000 m have been developed. Probes for carrying out chemical testing of soil and ground water are available for use in contaminated ground (see Robertson, Lunne and Powell, 1995 [79]).*

The selection of equipment and test procedures should be carried out in accordance with BS EN ISO 22476-1 for electrical cone penetrometers and BS EN ISO 22476-12 if using mechanical cones (no longer used in the UK), as well as BS EN 1997-2 and NA to BS EN 1997-2. The testing should be undertaken by specialist contractors.

## 39.2 Electrical cone penetration test

### COMMENTARY ON 39.2

*The basic principle of the electrical CPT is that a cylindrical probe, fitted to the lower end of a string of hollow rods, is pushed into the ground at a slow uniform rate by a static thrust. The probe has a cone at its base, which is fitted with a sensor, so that its resistance to penetration can be measured. Most probes incorporate a friction sleeve, by which the local frictional resistance can be measured, and in addition often incorporate a piezometer for measuring the pore water pressure in the vicinity of the cone and sleeve (see Lunne et al., 1997 [74] and Meigh, 1987 [80]). The probes have electrical sensors, or when including a piezometer CPTU, which can permit near continuous recording throughout the test. The CPT and CPTU test are widely used in-situ tests.*

Electrical cone or piezocone penetration equipment and method of testing should conform to BS EN ISO 22476-1, BS EN 1997-2 and NA to BS EN 1997-2. When undertaking piezocone tests, where penetration pore water pressure is measured, the probe should be fitted with a piezometer intake and pressure transducer.

Load sensors, pressure transducers and other instrumentation should be of suitable capacity and sensitivity for the ground conditions likely to be encountered, for example, in very soft clays and silts more sensitive cones with appropriate resolution accuracy, together with all the required corrections should be used. They should be calibrated regularly and proof of calibration should be available on-site (see BS EN ISO 22476-1). The test procedure should include a means to check that the probe in use has been correctly identified and is working satisfactorily.

*NOTE 1 There are generally two alternative positions available for the piezometer element:*

- a) *on the shoulder of the cone, just behind the cone; or*
- b) *on the face of the cone.*

*The first of these, on the shoulder, is given as the preferred location in BS EN ISO 22476-1. It allows the measured values of cone resistance to be corrected for errors induced by pore water pressures acting on the surfaces of the penetrometer and this correction is a requirement in BS EN ISO 22476-1 when determining geotechnical parameters in fine grained soils. The generated pore water pressures vary with the geometry of the penetrometer (see BS EN ISO 22476-1).*

*The pore water pressure measurements can vary substantially, depending on the location of the intake. The response appears to depend on the material being tested and its over-consolidation ratio. The optimum location depends on the soils to be investigated and the purpose of the investigation (see Lunne et al., 1997 [74] and Meigh, 1987 [80]).*

CPTs should not be carried out in isolation except where extensive experience of the site or similar materials is available. A number of exploratory holes should be put down adjacent to CPTs to ensure that correlations being used are valid for the particular strata being investigated; the number of these would be dependent on the variability of the ground, size of site and layout of investigation

*NOTE 2 In use, the probe is advanced at a uniform rate of penetration by thrust on the sounding rods and the electric signals from the various measuring devices are normally carried by a cable threaded through the penetrometer rods to the surface. Other systems are available, which either transmit the data to the surface using acoustics, or store the test data in the probe so that it can be downloaded when the probe is recovered at the end of each test. Data from the test is displayed for immediate assessment, recorded automatically at selected intervals by computer or data logger for later processing. Sole dependence on data that is recorded electrically, which cannot be assessed during or immediately after test completion, is not recommended.*

*NOTE 3 Penetrometer tests can be deflected off line by some ground conditions, leading to significant errors in the reporting of vertical depths. BS EN ISO 22476-1 specifies the use of inclinometers when undertaking testing in certain ground conditions and always if the results are to be used to determine geotechnical parameters. BS EN ISO 22476-1 sets classes of equipment related to the purpose of the test.*

*NOTE 4 The electrical cone penetration test is relatively quick to carry out and the results can be made available immediately following the completion of the test; it is also usually cheaper by comparison with boring, sampling and laboratory testing. However, no direct inspection of the ground is carried out, and all information regarding material type and properties is derived from essentially empirical correlations with the behaviour of the cone during penetration. The descriptions of soil types are reported from CPT/CPTU tests. The soil descriptions presented on CPT logs traditionally follow the format of those on exploratory holes (see Section 6), these are, however, not based on actual particle size distribution or plasticity assessment but on correlation of soil type with cone behaviour. The soil types in commonly used correlations use non-UK descriptive terminology. Consistency and relative density terms are used in accordance with different definitions to those for soils in Section 6.*

*NOTE 5 The results of a test are presented as plots versus depth of cone resistance, local friction and friction ratio (local friction divided by cone resistance), together with pore water pressure if a piezocone has been used in accordance with BS EN ISO 22476-1. The frequency of data recording can be varied to suit the needs of the investigation. An assessment of these data can give a useful indication of the ground profile, together with many parameters such as strength, relative density and modulus of elasticity. Many correlations are now available for a wide range of soils (see Lunne et al., 1997 [74] and Meigh, 1987 [80]) and others are constantly under development. For any site, however, it is important to ensure that the correlations being used are valid for the particular strata being investigated. Electrical cone penetration test data can also be used directly for design purposes e.g. pile capacity or driveability.*

*NOTE 6 The electrical cone and piezocone penetration test is commonly used as a rapid and economical means of interpolating the ground profile between boreholes. It can accurately detect the presence of thin soil layers of less than 100 mm thickness, which can easily be undetected by conventional boring and sampling. The test can reliably identify variations in strength across a site and with depth. The results can then be used to plan a programme of selective boring sampling and laboratory testing in zones of special interest. When the piezocone is used, dissipation tests, which monitor the decay of the porewater pressure measured by the cone during a pause in driving, can facilitate the assessment of the coefficient of consolidation and its variation across the site and with depth.*

When using any correlations for soil parameters from CPT/CPTU tests, it should always be ensured that the correlations being used are appropriate for the ground conditions being investigated. Ideally they should be validated by correlation to site-specific laboratory test data (see also BS EN 1997-2:2007 and NA to BS EN 1997-2). Any correlations used should be reported in the Ground Investigation report.

*NOTE 7 Some penetration test equipment can take piston samples in soft or loose soils from specific horizons (e.g. Mostap sampling, see 25.5.3) and to operate the Delft continuous sampler (see 25.6). The samples are used for strata descriptions and conventional laboratory testing. The equipment can also be used to install piezometers and to carry out various in-situ tests including the push-in pressuremeter and sampling, and environmental tests (see Lunne et al., 1997 [74]).*

### 39.3 Mechanical cone penetration test

#### COMMENTARY ON 39.3

*The older type of mechanical cone penetrometer (known as CPTM) measures the cone and friction resistance by means of a system of internal rods, which thrust against an hydraulic load capsule set at ground surface. Its use is standardized in BS EN ISO 22476-12. Mechanical penetrometers are occasionally used in very isolated sites, where the more sophisticated electrical read-out systems are not readily applicable, and for doing preliminary probing to assess whether the ground conditions are suitable for the use of the more expensive electrical probe (the probe can experience severe damage when penetrating some types of grounds).*

Two types of probe may be used: the mantle cone, which measures only cone resistance; and the friction jacket cone, which measures both cone resistance and local friction.

Probing should be carried out in accordance with BS EN ISO 22476-12, BS EN 1997-2 and NA to BS EN 1997-2.

*NOTE 1 The probe is pushed to the required depth by thrust on the outer penetrometer rods, the cone and friction sleeve having been tipped to make them slide into the closed position. Thrust is then applied to the inner pressure rods and measured, usually by a hydraulic load cell. The cone advances ahead of the body of the probe and has sufficient travel to enable a measurement to be taken of its ultimate cone resistance. In the friction jacket cone, further travel of the cone makes it engage with the friction sleeve. Both cone and friction sleeve are now advanced and have sufficient travel to give a measurement of the combined resistance of the cone and friction sleeve. This procedure is repeated at regular intervals of depth, which are normally 0.2 m.*

*NOTE 2 In the UK the mechanical cone is now almost completely superseded by the electrical cone.*

## 40 Flat dilatometer test

### COMMENTARY ON CLAUSE 40

*The flat dilatometer test, more commonly known as the Marchetti Dilatometer (or DMT), is a simple, robust device with the potential to give a range of soil properties as well as to be used directly in semi-empirical design procedures. It consists of a stainless steel blade, 250 mm long, 94 mm wide and 14 mm thick with a tip angle of 16° having a flat, circular steel membrane mounted flush on one side. It is inserted vertically on the end of a set of rods to pre-determined depths in the ground. A test is performed by inflating the membrane by gas pressure and the movement of the membrane is measured and the pressures required to start it moving and to expand it a given distance are recorded. Readings are repeated at each depth interval down the profile (typically 200 mm). The pressure readings are corrected for stiffness effects, etc. and converted to dilatometer parameters; these parameters are then correlated to various soil/geotechnical parameters related to ground behaviour.*

DMT testing should be specified and carried out in accordance with ISO/TS 22476-11, BS EN 1997-2 and NA to BS EN 1997-2. Any correlations used should be justified and reported in the Ground Investigation report.

*NOTE 1 The DMT is suitable for use in sands, silts and clays, where the grains are small compared to the membrane diameter (60 mm), with a very wide range of strengths, from very soft to very stiff clay or weak rock. It is not suitable for gravels, although the blade is robust enough to pass through gravel layers of no more than about 0.5 m thickness.*

*NOTE 2 Unless hindered by impenetrable layers, it is a very good profiling tool. When specified and used correctly, reliable and repeatable data can be obtained. A wide range of correlations to standard and advanced geotechnical parameters is now available and test data can be used directly in the design of foundations. However, the confidence level in the selection of parameters for correlation purposes is to some extent related to experience in the interpretation of the DMT data in the type of deposits being investigated.*

## 41 Standard penetration test

### COMMENTARY ON CLAUSE 41

*The main reason for the widespread use of the standard penetration test (SPT) is that it is simple and inexpensive and can be carried out by the drilling crew. The test uses a thick-walled sample tube, the outside diameter of which is 50 mm. This is driven into the ground at the bottom of the borehole by blows from a standard weight falling through a standard distance. The blow count (N value, number of blows to drive the sampler 450 mm) gives an indication of soil strength, relative density and other parameters which can be inferred; these are, at best, approximate, but they might give a useful guide in ground conditions where it might not be possible to obtain borehole samples of adequate quality, e.g. gravels, sands, silts, clay containing sand or gravel and weak rock. In conditions where the quality of the "undisturbed" sample is suspect, e.g. very silty or very sandy clays, or very stiff clays, it is often advantageous to alternate the sampling with standard penetration tests to check the strength. If the samples are found to be unacceptably disturbed, it might be necessary to use a different methods. The small sample that is recovered from the SPT split sampler is likely to have suffered disturbance but can normally be used for identification purposes.*

The standard penetration test is a dynamic penetration test and should be carried out in accordance with BS EN ISO 22476-3, BS EN 1997-2 and NA to BS EN 1997-2. The records should be presented on borehole logs as blow counts for all increments, with the N value reported in the standard way.

*NOTE 1 Even minor variations from the specified procedure, including the preparation prior to carrying out the test, can seriously affect the results. Maintaining verticality of the SPT rods at the top of the borehole and the hammer assembly is particularly important to ensure consistent energy imparted to the anvil. Annual calibration of the hammer is required by BS EN ISO 22476-3. Typical Energy Ratio (Er) values for UK hammers vary widely. These variations are particularly important if the test result is to be used for quantitative purposes; if the Energy Ratio (Er) obtained from this calibration differs too much from 60%, steps to stop using that hammer might be appropriate.*

When the test is carried out in coarse soils below groundwater level, the soil can become loosened, even when the test is carried out in strict accordance with BS EN ISO 22476-3, BS EN 1997-2 and NA to BS EN 1997-2 and the borehole has been properly prepared. (This is particularly problematic in sands and silty sands where groundwater flow into the borehole (piping) can lead to “blowing sand” conditions.) Boreholes should be kept topped up with water to a level at least as high as the relevant groundwater level; a suitably gentle shelling action should be used, and undersize boring tools used to reduce the suction pressure when raising the tool.

*NOTE 2 In certain circumstances where very low blow counts are recorded, equivalent to N values of say 5 or less, it can be useful to continue driving the sampler beyond the 450 mm distance specified, for a further 300 mm, recording blows for 75 mm increments as with the main test drive. Although this is not a standard penetration test, and is not to be regarded as such, it might at least give an indication as to whether the deposit is really as loose as the standard test indicates.*

When the test is being performed in gravel or coarser soil or in rock, the cutting shoe of the split-barrel sampler should normally be replaced by a solid cone of the same outside diameter and an included angle of 60° and then recorded as SPT(C).

*NOTE 3 The measured N value can be correlated with other soil parameters and with the performance of structures. The test is usually carried out in sands and gravels, but it has also been used to assess the strength of other soils (silts and clays) and of weaker rocks (e.g. Southern Province Chalk Subgroup).*

When there is good reason to believe that unrealistically low values are being recorded, then an alternative testing method, which can be performed independently of a borehole, should be used, e.g. the dynamic or static probing described in 38.1 and 39. In the construction of bored piles, the test is sometimes carried out in boreholes considerably larger in diameter than those used for ground investigation work. The result of the standard penetration test is dependent upon the diameter of the borehole, and so these tests should not be regarded as standard penetration tests. They might, however, provide useful information to a piling contractor, particularly if the contractor has considerable experience in their use.

Correlation of the test results with other geotechnical parameters should be made with great care. BS EN 1997-2:2007, Annex F gives some examples of interpretation; any correlations and corrections (see BS EN ISO 22476-3 and BS EN 1997-2 for discussion on these) used should be reported in the Ground Investigation report. In particular, correction of N values to take account of the Energy Ratio of individual hammers should take account of such a procedure not having been used in the original data reviews/correlations.

*NOTE 4 SPT results and soil parameter correlations derived from data from other countries might not correlate with results from SPTs derived in accordance with previous UK standards. However, with the adoption of BS EN ISO 22476-3, this situation is less likely in future.*



## 42 Vane test

### COMMENTARY ON CLAUSE 42

*Vane testing in the field usually takes the form of either the “field vane” or “hand vane” for use in fine grained soils. The vane test comprises a cruciform vane on the end of a solid rod which is forced into the soil and then rotated at a constant rate of between 6°/min and 12°/min. In the field vane test the torque required to rotate the vane is recorded as the vane rotates; in the case of the hand vane a maximum reading is recorded. The field vane test is continued for a given rotation and can be related to the shear strength of the soil. The test can be extended to measure the remoulded strength of the soil. This is done by turning the vane through 10 complete rotations. A period of 5 min is permitted to elapse after which the vane test is repeated in the normal way.*

The field vane test can be performed either in the base of a borehole or by penetration from the ground surface and should be carried out in accordance with BS EN ISO 22476-9, BS EN 1997-2 and NA to BS EN 1997-2; the friction on the rods above the vane should be kept to a minimum.

*NOTE 1 The degree of disturbance caused by rotating the vane differs from that obtained by remoulding a sample of clay in the laboratory and the numerical value of the sensitivity of the clay determined by these procedures is not strictly comparable with the results obtained from laboratory triaxial tests.*

The penetration technique may be used ahead of the borehole where the vane and a protective casing are forced into the ground by jacking. At the required depth, the vane should be advanced a short distance ahead of the protective casing, the test conducted and the casing and vane subsequently advanced to the next required depth. With this type, it is not always possible to penetrate to the desired stratum without the assistance of pre-boring.

The test should normally only be carried out in homogeneous uniform, fine, fully saturated soils, having an undrained shear strength up to about 100 kPa. The results are questionable in stronger clays or if the soil tends to dilate on shearing or is fissured. Results are unreliable in materials with significant coarse silt or sand content. When operating in a borehole then the borehole should be kept topped up with water in soft, layered or sensitive soils.

*NOTE 2 The undrained shear strength determined by an in-situ vane test is normally not equal to the average value measured at failure in the field, e.g. in the failure of an embankment on soft clay. The discrepancy between field and vane shear strengths is found to vary with the plasticity of the clay and other factors (see Bjerrum, 1973 [81] and Aas, Lacasse, Lunne and Hoeg, 1986 [82]). Various corrections are considered in BS EN 1997-2:2007, Annex I.*

*NOTE 3 The main advantage of the vane test is that the test itself causes little disturbance of the ground and is carried out below the bottom of the borehole or vane housing in virtually undisturbed ground. This is particularly apparent in sensitive clays, because higher shear strengths tend to result from the in-situ vane test than from laboratory tests on samples obtained with the general purpose sampler described in 25.4. If the test is carried out in soil that is not uniform and contains only thin layers of laminations of sand or stiff to very stiff silt, the torque might be misleadingly high. The presence of rootlets in organic soils, and also of coarse particles, can lead to erroneous results.*

Small hand-operated vane test instruments are available for use in the sides or bottom of an excavation. The hand vane tests should be regarded as index tests.

*NOTE 4 Hand vane instruments are produced by several manufacturers. Some do not have the vane height to width ratio of 2 'standardized' for field vanes and the means of calibrating the torque measuring device and/or the basis for correlating with shear strength varies between the instruments is not always apparent.*

*NOTE 5 Neither the hand vane equipment nor the test procedure is explicitly covered by BS EN ISO 22476-9 or BS 1377-9:1990. For a useful review of the test, see the New Zealand Geotechnical Society's guidelines [83], which includes a suggested specification item and test method.*

## 43 Pressuremeter tests

### COMMENTARY ON CLAUSE 43

*A pressuremeter can be used to give an assessment of the in-situ stress, stiffness and strength of the ground. The device is cylindrical with a flexible membrane over part of the outside curved surface. It imposes a uniform pressure on a borehole wall (see Mair and Wood, 1987 [84]), and the applied pressure and the resulting deformation are recorded.*

*There are two approaches to the use of pressuremeters in ground investigations. The first is based on the methods developed by Ménard (see Baguelin, Jezequel and Shields, 1978 [85]) in which the pressuremeter is used to obtain design parameters directly. The second is to analyse pressuremeter tests to give the properties of the ground.*

### 43.1 General

Pressuremeter tests are specialist tests and should only be carried out by specialist contractors.

### 43.2 Pressuremeters

#### COMMENTARY ON 43.2

*Pressuremeters fall into three categories: those that are lowered into pre-bored holes, those that are drilled or self-bored into place and those that are pushed in. They are normally between 40 mm and 100 mm in diameter and up to 1 m long, with the expanding section being between 5 and 7 times the diameter of the instrument. Versions do exist at 142 mm diameter. The displacement capacity of the instrument is a function of the instrument design but exceeds 10% of the instrument diameter, much more in the case of a pre-bored hole pressuremeter because of the clearance necessary to fit it into the hole and much more in the case of pushed-in pressuremeters as their expansion needs to override the disturbance caused by their insertion procedure. There are three main pressure capacities: 0 MPa to 4 MPa for soils, 0 MPa to 10 MPa for weaker rocks, and 0 MPa to 20 MPa for weak to medium strong rocks.*

#### 43.2.1 Pre-bored pressuremeters

##### COMMENTARY ON 43.2.1

*Pre-bored pressuremeters are mainly single expanding cell systems in which the radial or diametrical displacement is measured directly with transducers mounted in the instrument. The membrane is inflated with gas or oil, and the pressure measured with a transducer mounted in the instrument.*

Pre-bored pressuremeters (including high pressure dilatometers) should be lowered into pockets drilled specifically for the tests. The Ménard pressuremeter (see Baguelin, Jezequel and Shields, 1978 [85]) consists of three expanding cells connected to the surface by drill rods and flexible hoses. Other types of pre-bored hole pressuremeters (see Clarke, 1994 [86]) should be carried out in accordance with BS EN ISO 22476-5, BS EN ISO 22476-7 and BS EN ISO 22476-8, as appropriate, and BS EN 1997-2 and NA to BS EN 1997-2.

### 43.2.2 Self-bored pressuremeters

#### COMMENTARY ON 43.2.2

*Self-bored pressuremeters are single cell instruments attached to a drilling head (see Windle and Wroth, 1977 [87] and Withers, Schaap and Dalton, 1986 [88]) so that they can be bored into the ground. The head contains a drill cutter, turned by inner rods that pass through outer rods. The outer rods connect the instrument to the surface and are used to push the probe into the ground. Mud or water is pumped down the inner rotating rods and back up the annulus between the inner and the outer rods. This removes the soil arisings from the cutter but retains the in-situ pressure on the soil. Radial displacement of the membrane is measured directly with transducers mounted within the instrument. The membrane is inflated with gas or oil under pressure, which is also measured with a transducer mounted in the instrument.*

Self-bored pressuremeter testing should be specified and undertaken in accordance with BS EN ISO 22476-6, BS EN 1997-2 and NA to BS EN 1997-2.

### 43.2.3 Pushed-in pressuremeters

#### COMMENTARY ON 42.2.3

*These pressuremeters are a single cell instrument commonly, but not always, mounted behind an electric cone penetrometer (see Withers, Schaap and Dalton, 1986 [88]). The membrane is usually inflated by oil or water under pressure, ideally measured by a transducer mounted in the instrument. Displacement of the membrane can be measured directly by transducers within the instrument, recording and showing radial displacement or can be by volume change measurements.*

The push-in pressuremeter testing should be undertaken in accordance with BS EN ISO 22476-8, BS EN 1997-2 and NA to BS EN 1997-2.

## 43.3 Calibrations

For all types of pressuremeter calibrations should be undertaken in accordance with the relevant standard.

*NOTE* There are three groups of calibrations (see Clarke, 1994 [86] and Clarke and Smith, 1992 [89]):

- strain transducer or line volume calibrations;
- membrane stiffness; and
- membrane compression.

*The membrane stiffness and compression calibrations are in fact corrections that are applied to the measured test data. The membrane stiffness correction accounts for the pressure required to overcome the membrane's inherent stiffness and is assessed by inflating the instrument in air. The membrane compression correction actually accounts for compliance of the whole pressuremeter and represents adjustment to the measured displacements for apparent movements due to pressurising of the pressuremeter probe. This correction is assessed by inflating the instrument in a steel or aluminium cylinder of known stiffness.*

## 43.4 Test procedures

#### COMMENTARY ON 43.4

*Tests can be either stress-controlled or strain-controlled. In stress-controlled tests there are increments of pressure during the loading phase, each increment being held for a specified time or alternatively a continuous loading may be applied. A strain-controlled test is also under stress control initially but a feedback system is used to ensure that the displacement of the membrane satisfies a pre-set strain rate (see Clarke and Smith, 1992 [89]).*

The Ménard method is a standardized test procedure based on a stress-controlled (incremental loading) test (see Baguelin, Jezequel and Shields, 1978 [85]); it should be carried out in accordance with BS EN ISO 22476-4, BS EN 1997-2 and NA to BS EN 1997-2. The objective is that method-specific parameters are obtained that can be used directly in design formulae developed from observations of full scale tests.

*NOTE 1 It has become practice in the UK to carry out Ménard-style tests using other types of equipment but following the Ménard testing procedure. These are referred to as emulated Ménard tests, and have been performed using, for example, high pressure dilatometers (HPD) and purpose-built smaller diameter instruments.*

*NOTE 2 Except in the Ménard test, it is common practice to carry out at least one unload reload cycle within a test from which values of stiffness can be obtained. In general, two or three unload reload cycles might be preferable and if included they yield data about the shear modulus and the way in which the shear modulus varies with the strain excursion.*

*NOTE 3 Pressuremeters can be used in most ground conditions, but not all pressuremeters can be used in any one ground condition. The results from any individual test depend on the equipment used and the procedures adopted for installation, for testing and for interpretation. This means that results from different tests might not necessarily be compatible. Prebored hole pressuremeters conforming to BS EN ISO 22476-4, BS EN ISO 22476-5 and BS EN ISO 22476-7 can be used in most soils and rocks with the exception of some very soft soils. The results obtained depend on the quality of the pre-drilling. Cambridge type self-boring pressuremeters conforming to BS EN ISO 22476-6 can be used in all clays, silts and sands provided they do not contain excessive amounts of gravel size particles. It might be necessary with the self-boring pressuremeter to use a separate drilling rig to clear obstructions encountered during self-boring. The weak rock self-boring pressuremeter is an upgraded version of the self-boring pressuremeter with thicker membrane, slightly oversize cutting shoe, and rock-roller or other heavy duty cutter. It can be used in dense sands, very stiff clays and weak rocks, although sometimes self-boring gives no better data than a correctly installed pre-bored hole pressuremeter. This instrument has to be used with a rotary rig. The cone pressuremeter can be used in those soils into which it is possible to push a cone.*

*NOTE 4 Theories of cavity expansion are well documented (see Clarke, 1994 [86]). The interpretation of a test is based on these theories but the parameters obtained might be empirical. Estimates of in-situ stress can be obtained from self-bored pressuremeter tests and in some cases prebored hole tests (see Marsland and Randolph, 1977 [90]).*

*NOTE 5 Average cavity stiffness can be obtained from unload-reload cycles from all pressuremeter tests (see Mair and Wood, 1987 [84]). Recent developments in interpretation show that the average cavity stiffness can be converted to a material stiffness (see Jardine, 1992 [91]). The values of stiffness vary with the strain and stress level over which they are carried out. The reliability of interpretations of deformation modulus, therefore, require the influence of strain magnitude on the modulus to be assessed and in soils where drainage occurs during a test the influence of changes in effective stress on the deformation modulus needs to be considered. Undrained shear strength can be obtained directly from self-boring pressuremeter tests and estimated from other pressuremeter tests (see Clarke, 1994 [86], Withers, Schaap and Dalton, 1986 [88] and Powell and Shields, 1995 [92]). Angles of friction and of dilation of sands can be determined from self-bored pressuremeter tests (see Hughes, Wroth and Windle, 1977 [93] and BS EN ISO 22476-6) and estimated from pushed in pressuremeter tests (see Powell and Shields, 1997 [94] and BS EN ISO 22476-8).*

## 44 Field density

### 44.1 General

#### COMMENTARY ON 44.1

*The bulk density of soil can be measured by a range of field tests which comprise the removal of a representative sample of soil from the site and then the determination of its mass and the volume it occupied before being removed. The variations lie in the several procedures used for measuring the volume and these depend upon the nature of the soil being tested. In coarse grained soils it forms the "field" element of the relative density test, the other two elements often being carried out in the laboratory.*

Safe physical access to the soil in situ should be provided for all test methods in 44.2 to 44.5. The water content of the sample should be representative. Ideally, the weighing should be done on-site; if this is not possible, the entire sample should be preserved until it can be weighed, taking care to avoid loss of water.

*NOTE The tests can be of limited accuracy and it might be necessary to take the average of at least three determinations to obtain a significant result.*

### 44.2 Sand replacement test method

Sand replacement tests should be carried out in accordance with BS 1377-9, which describes two test variations (see BS 1377-9:1990, 2.1 and 2.2). The first is used for fine and medium-grained soils, as defined in BS 1377. The second is suitable for fine, medium and coarse-grained soils. These test methods are unsuited to soils containing a high proportion of coarse gravel or larger particles. The method should not be used in soils where the volume of the hole cannot be maintained constantly. It also loses accuracy in soils where it is difficult to excavate a smooth hole because the test sand added into the hole cannot easily occupy the full volume.

### 44.3 Water replacement test method

The water replacement test method should be carried out in accordance with BS 1377-9:1990, 2.3. The method is normally used in coarse and very coarse soils (including rockfill) when the other methods for determining the field density are unsuitable because the volume excavated would be unrepresentative. It consists of excavating a hole large enough to obtain a representative sample, lining the hole with flexible polyethylene or similar sheeting and then determining the volume of water required to fill the hole.

The accuracy of the results of this test can be enhanced by attention to the following details:

- a) the hole should be made as large as possible;
- b) the sides of the hole should be made as smooth as possible;
- c) as thin a gauge of polyethylene as possible should be used, consistent with it not puncturing too easily.

#### 44.4 Core cutter test methods

The core cutter test method should be carried out in accordance with BS 1377-9:1990, 2.4. The method depends upon being able to drive a cylindrical cutter into the soil without a significant change of density and retaining the sample inside it so that the known internal volume of the cylinder is completely filled. It is, therefore, restricted to fine soils that do not contain gravel and are sufficiently cohesive for the sample not to fall out, and to chalk soils. It might be preferable in cohesive and sensitive soils to trim and push the cutter rather than drive it.

#### 44.5 Nuclear test methods

Nuclear test methods should be carried out in accordance with BS 1377-9:1990, 2.5. These do not measure density directly; calibration curves should be established for each soil type, which involves measuring the densities of representative samples of the soils concerned by the container method or one of the conventional in-situ methods given above. Once this has been done and provided there are no significant changes in soil type, the method is very much faster than the others. It is, therefore, most suited to jobs where there is a continuous need for density determinations over a long period and where the soil types do not vary to any significant extent. The density determined by these methods is not necessarily the average density within the volume involved in the measurement. The equipment utilizes radioactive materials and appropriate safety precautions should be taken.

*NOTE The major use of this test is in the control of the compaction of earthworks. It is also used in connection with the design of road and airfield pavements and in the control of the compaction of sub-grades on which they rest. It can be used for the determination of natural in-situ density, where it is difficult or impossible to take undisturbed samples.*

#### 44.6 Electrical test method

##### COMMENTARY ON 44.6

*Electrical test methods are beginning to become available and, as with the nuclear methods in 44.5, they do not measure the density directly. Some measure the electrical dielectric properties and moisture levels of compacted soil using high, radio frequency traveling between darts driven into the soil being tested, others adopt electromagnetic techniques. The results are correlated with estimates of the in-situ density using in-built "soil models".*

Site-specific checks using alternative methods should be undertaken to ensure reliability of the results.

Testing of this type should be undertaken in accordance with the manufacturers' guidance (as many are not currently standardized).

*NOTE The major use of this test is in the control of the compaction of earthworks. It is also used in connection with the design of road and airfield pavements and in the control of the compaction of sub-grades on which they rest. It can be used for the determination of natural in-situ density, where it is difficult or impossible to take undisturbed samples.*

### 45 In-situ stress measurements

##### COMMENTARY ON CLAUSE 45

*Measurement of in-situ stress in soils and rocks may be made, although the equipment used means that the results only normally provides an estimate of stress and not an exact measurement. To enable both total and effective stresses to be estimated, it is usual to measure the pore water pressure in addition to the total stress.*

*The stresses existing in a ground mass before changes caused by the application of loads or the formation of a cavity within the mass are referred to as the initial in-situ state of stress. These stresses are the result of gravitational stress and residual stresses related to the geological history of the mass.*

*Data on the initial in-situ state of stress in rock and soil masses before the execution of works are important in design. The most favourable orientation, shape, execution sequence and support of large and complex underground cavities, and the prediction of the final state of stress existing around the completed works, are all dependent on knowing the initial in-situ state of stress. Measurements of in-situ stress have shown that in many areas the horizontal stresses exceed the vertical stress, which in turn often exceeds that calculated, assuming that only gravity is acting on the ground mass.*

## 45.1 Stress measurements in rock

### 45.1.1 General

Over-coring should be used for measurement within the rock mass, whereas slotting should be used for surface stress measurements. With the exception of the static equilibrium method (see 45.2.5), the methods described are based on stress changes, achieved by over-coring or slotting a previously instrumented test area. Measurements taken should be adjusted to take account of the redistribution of stresses as a result of formation of the borehole or slot and when the measurement is made in the zone of influence of the main access, such as an adit. Stress measurements may also be determined from the measurement of displacements of the walls of a tunnel, or of an exploratory adit, close to the working face.

*NOTE The techniques often require that the material in which the measurements are made behaves in a near elastic, homogeneous and isotropic manner and that it is not prone to swelling as a result of drilling water, or excessively fractured. Analyses are available that evaluate measurements made in anisotropic material but these are not widely used. For the over-coring methods, the elastic behaviour is assumed to be reversible, the elastic constants being obtained from field or laboratory tests.*

Stress measurements may be made using electrical strain gauges, photoelastic discs, solid inclusions and systems for measuring the diametrical change of a borehole. Some equipment is designed to measure stress change with time, or stress change due to an advancing excavation, whereas other equipment is designed to obtain an instantaneous measurement of stress. The technique selected should be chosen in relation to the rock material, mass quality and water conditions.

To determine the triaxial state of stress at a given point, measurement should be made in at least six independent directions. It is, however, desirable to have the extra data for better evaluation by statistical methods of error distribution.

The report on the results of in-situ stress measurement should include the following:

- a) location of test and direction and depth of the drill holes, method of drilling and diameters of cores;
- b) depth below ground level of the point of measurement;
- c) geological description of the rock mass;
- d) strain readings to the nearest 10 micro strain;
- e) the modulus of elasticity,  $E$ , and Poisson's ratio,  $\nu$ , of the rock determined from static laboratory testing of core preserved at in-situ water content, over the appropriate stress path, from each stress measurement area;

- f) the six components of stress ( $\sigma_x, \sigma_y, \sigma_z, \tau_{xy}, \tau_{yx}, \tau_{zx}$ ) at each point to the nearest 100 kPa;
- g) the three principal stresses and the directions (to the nearest degree), related to both a borehole or adit axis system and a global axis system;
- h) colour photographs of the cores or test location (see Annex H); and
- i) date of measurement and data at which excavation passes the point of measurement.

#### 45.1.2 Determination of the in-situ triaxial state of stress in rock

The most widely adopted method for the determination of the in-situ triaxial state of stress in one set of measurements uses the CSIRO hollow inclusion stress cell. The strains are measured over relatively small gauge lengths, approximately 10 mm, on a small test area, and should, wherever possible, be correlated and cross-checked with data obtained from other tests involving a larger test area, such as a flat jack test in the side walls of a suitably shaped and oriented adit.

*NOTE 1 The method is one of over-coring a cell containing nine or twelve electrical strain gauges installed on the walls of a pilot drillhole. The test is relatively cheap and quick to perform. A full description of the equipment and the test procedure is given in the standard instruction manual from Mindata [95] and the ISRM document Suggested methods for rock stress determination [N2].*

*NOTE 2 The stress cell, shown in Figure 11, contains three or four oriented rosettes each of which has three gauges and a temperature compensating gauge or thermistor. Nine or twelve independent strains are recorded, of which six are used to determine the total state of stress, and the other measurements are used as a check and for estimating errors.*

*A second instrument that can be used in deep water-filled boreholes drilled from the surface is the Borre Probe. This has been used in the UK to depths of up to 250 m (see Whittlestone and Ljunggren, 1995 [96]). The probe shown in Figure 12 contains three oriented rosettes, a temperature gauge and a dummy gauge. Strain changes during overcoring are recorded by a downhole data logger without connection to the surface.*

It is usual when carrying out measurements from underground openings to carry out several tests in each borehole at increasing depths in order to investigate the change in stress distribution as a result of excavation. If possible, two holes should be drilled at orthogonal directions to take account of any anisotropic characteristics of the rock.

*NOTE 3 All methods require a knowledge of the modulus of elasticity and Poisson's ratio of the rock. These can be obtained by biaxial testing of the overcore sample in a Hoek cell in the field, or laboratory testing of the core preserved at in-situ water content, under the appropriate stress path.*



Figure 11 Measurement of in-situ stress – CSIRO cell

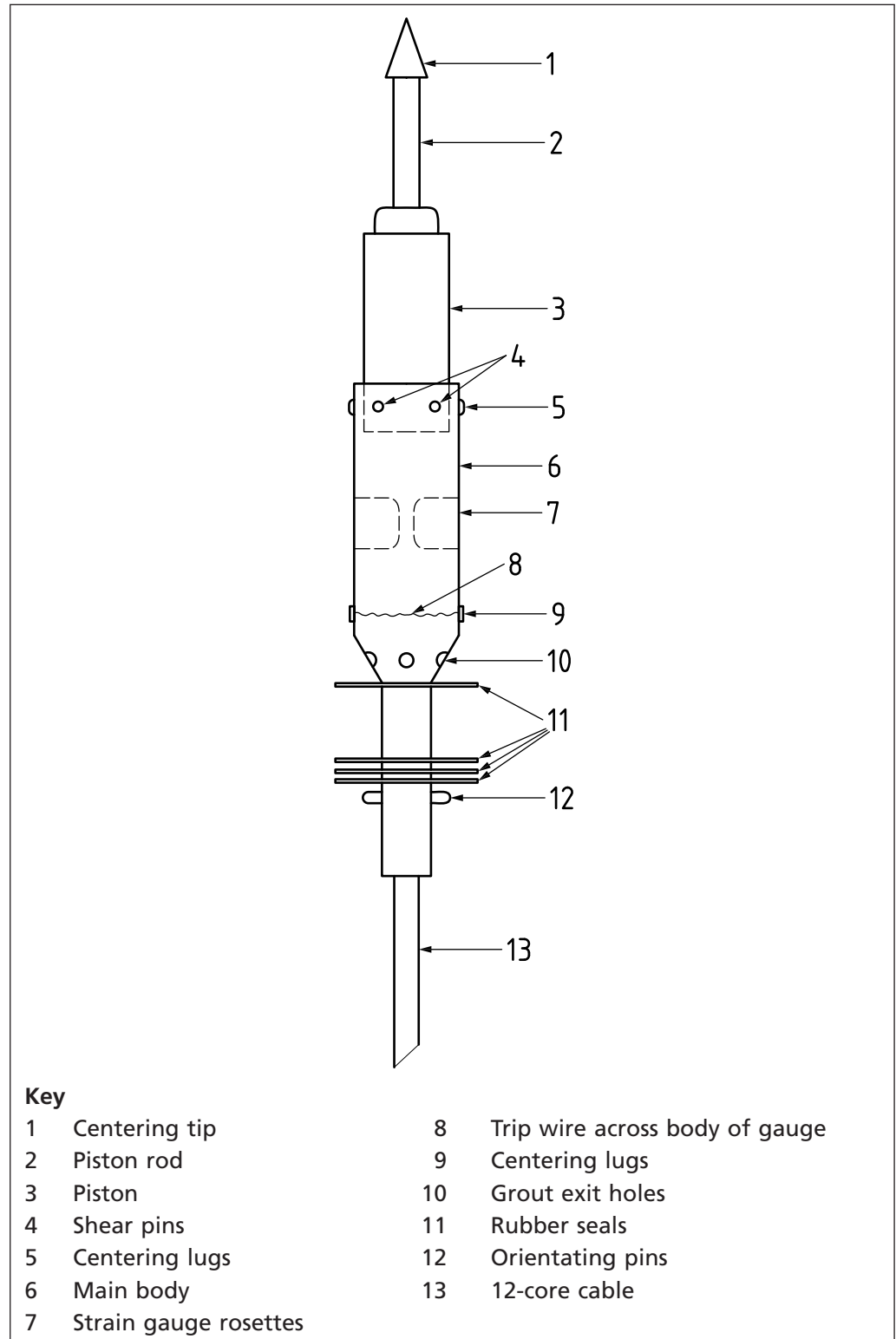
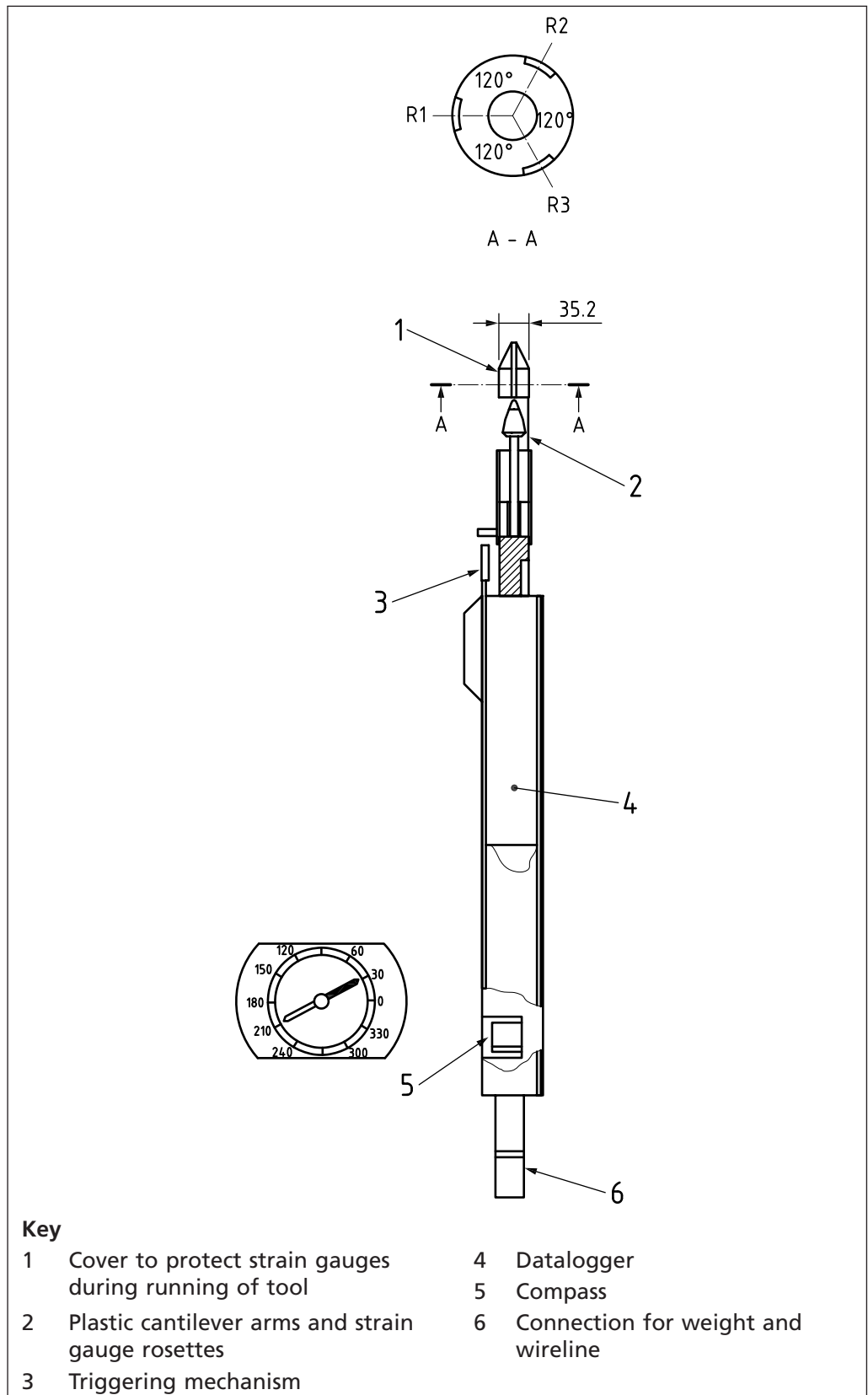


Figure 12 Measurement of in-situ stress – Borre probe



### 45.1.3 Biaxial stress measurements in rock

When measuring biaxial stresses in rock, the USBM (United States Bureau of Mines) borehole deformation gauge is often used; when using this technique, the details of installation and the test procedure found in the ISRM document *Suggested methods for rock stress determination* [N2] should be followed.

The equipment comprises three strain gauges bonded to cantilevers that measure the changes in pilot hole diameter during overcoring. Stress components in the plane perpendicular to the borehole can be evaluated from the results. To enable the resolution of the total state of stress, measurements should be made in three mutually perpendicular holes drilled into one area. The gauge may be used in water-filled boreholes, provided the water pressure is less than 60 kPa.

### 45.1.4 Uniaxial stress measurements near a surface using a flat jack

When undertaking uniaxial stress measurements, the equipment and procedures described in the ISRM document *Suggested methods for rock stress determination* [N2] should be followed.

By means of a saw or overlapping holes, a slot should be cut into a rock surface provided by an adit or prototype underground excavation. The stresses previously acting across the slot are relieved as the rock moves into the slotted void. This movement should be measured by the convergence of marked points that are fixed on either side of the slot before it is formed. A suitable hydraulic flat jack should be embedded in the slot and the pressure in the jack increased until the convergence of the datum points is cancelled. If creep can be ignored, the cancellation pressure should be related to the stresses that were acting normally on the plane of the slot before it was formed.

The stresses measured by this means are those parallel and near to the rock surface in which the slot is cut. The location of the adit should be such that its axis is driven in a direction nearly parallel to that of the proposed prototype excavation and as close as possible into the zone of interest. Excavation of the test zone in the adit should be carefully carried out, preferably by hand excavation or using smooth blasting techniques, and the period between excavation and measurement should be as short as possible. A typical section of a flat jack test is shown in Figure 13.

The technique measures only tangential stress near the surface of an excavation. As the flat jack stresses a greater mass of rock, the results tend to give a better average measurement than can be obtained using a smaller gauge length. This method can be used in ground where other methods are not suitable. To estimate the triaxial state of in-situ stress, at least six flat jack tests should be carried out in independent directions.

*NOTE All three methods require knowledge of the elastic properties. These can be obtained by biaxial testing of the over-core sample in a Hoek cell.*

### 45.1.5 Static equilibrium method

*NOTE The static equilibrium method of in-situ stress determination is based on the static equilibrium requirement that the total load on a sufficiently large area remains constant, even after an opening, such as mine drift, is made in the area. It does not require that the rock be elastic, homogeneous or isotropic.*

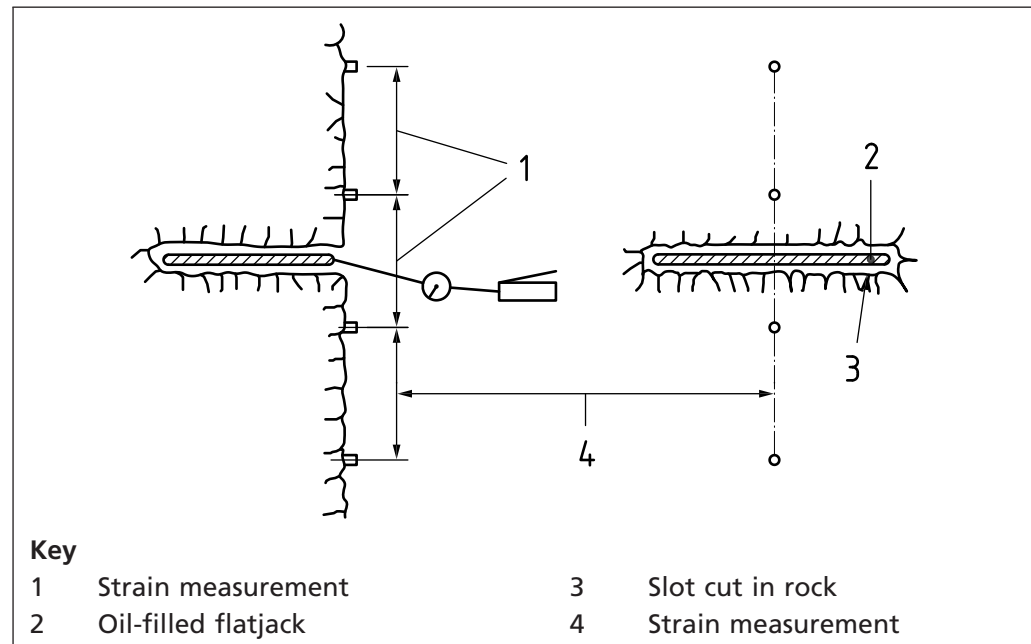
### 45.1.6 Hydraulic fracturing technique

#### COMMENTARY ON 45.1.6

*Hydraulic fracturing (see Haimson, 1978 [97]) provides a determination of the maximum and minimum stresses in a plane perpendicular to the drillhole. The particular application of the technique has been in deep drillholes and requires no knowledge of the elastic properties of the rock.*

When undertaking this test, the technique described in the ISRM document *Suggested methods for rock stress determination* [N2] should be followed.

Figure 13 Measurement of in-situ stress – Flat jack equipment – Typical layout



## 45.2 Stress measurements in soils

### 45.2.1 General

The response of soil masses to applied loads should be made by obtaining reliable data on their strength and deformation characteristics; as these are stress-dependent, a knowledge of the in-situ state of stress assists in their evaluation by laboratory testing.

*NOTE* Direct in-situ measurements of the initial state of stress in soils is difficult because the disturbance created by gaining access to the ground mass is usually non-reversible, as well as being several times that produced by a stress-relieving technique. Most techniques that have been developed suffer from the disturbance that their instruments create in the ground on insertion.

*It is usual to measure horizontal stress only and to make assumptions concerning the level of vertical stress from overburden depth. Total stress only may be measured, so to determine the effective stress conditions the pore water pressure at the test level has to be measured or assumed. Methods of determining pore water pressure in the field are discussed in Clause 52.*

### 45.2.2 Hydraulic push-in pressure cells

Measurement of total stress in soft to stiff clays should be carried out using thin rectangular hydraulic cells, "push-in spade shaped cells", carefully jacked into the ground (see Tedd et al., 1989 [98]). The insertion of the cell into the ground generates a pressure in the cell which decays with time to a constant value equal to the total stress in the ground plus an over-read caused by the disturbance resulting from the insertion of the cell into the ground. The cell reading is adjusted for the over-read by a correction factor related to the undrained shear strength of the soil.

*NOTE* Measurement of vertical and horizontal total stresses can also be achieved from vertical boreholes in soft clays using the BRE miniature push-in earth pressure cells (see Watts, 1991 [99]).

### 45.2.3 Contact stress measurement

The self-bored pressuremeter (see 42.1.2) and Camkometer may be used to reduce disturbance on insertion to a minimum by fully supporting the ground they penetrate. As pressure is applied to jack the cell into the ground, a cutting tool slowly rotates and gentle water flush removes surplus materials. Once installation has been completed the Camkometer electrical load cells measure the contact pressure, from which an estimate of total horizontal in-situ stress is obtained. The pressuremeter gives an estimate of the horizontal stress from the lift-off pressures of the membrane (see Clarke, 1994 [86]). Facilities are available to measure pore water pressure with the same instruments. Ground conditions might limit the use of this technique.

### 45.2.4 Hydraulic fracturing

Hydraulic fracturing (see Bjerrum and Anderson, 1972 [100]) may be used to estimate minimum total horizontal stresses in a deposit of soft to firm clay (one where the expected horizontal stress is lower than the vertical). A length of borehole is sealed and a pumping-in test carried out. Pressure in the test zone is increased in increments until a sudden increase in water flow occurs, at which time it is assumed that tensile failure has occurred in the ground. The pressure at which failure takes place is related to the minimum in-situ stress by soil properties.

## 46 Bearing tests

### 46.1 Vertical loading tests

#### 46.1.1 General

In-situ vertical loading tests can be made by measuring the applied load and penetration of a rigid flat object of known dimensions being pushed into a soil or rock mass and should be carried out in accordance with BS 1377-9:1990, 4.1, for soils (see also the ISRM document *Suggested methods* [55]). The test should be carried out in shallow pits or trenches or at depth in the bottom of a borehole, pit or adit (see Figure 14 and Figure 15). In soils, the test should be carried out to determine the shear strength and deformation characteristics of the material beneath the loaded plate. The ultimate load is often unattainable in rocks, where the test is more frequently used to determine the deformation characteristics.

*NOTE 1 The test can be carried out either under a series of maintained loads or at a constant rate of penetration (see Powell, et al., 1989 [101] and Marsland and Powell, 1985 [102]). In the former, the ground is allowed to consolidate under such a load before a further increment is applied; this yields the drained deformation characteristics and, if the test is continued to failure, also the strength characteristics. In the latter, the rate of penetration is often such that little or no drainage occurs, and the test gives the corresponding undrained deformation and strength characteristics.*

*NOTE 2 The results of a single loading test apply only to the ground that is significantly stressed by the plate; this is typically a depth of about one and a half times the diameter or width of the plate. The depth of ground stressed by a structural foundation is usually far greater than that stressed by the loading test and the results of loading tests carried out at a single elevation do not normally give a direct indication of the allowable bearing capacity and settlement characteristics of full-scale structural foundation.*

To determine the variation of ground properties with depth, a series of plate tests should be carried out at different depths. These should be carried out such that each test subjects the ground to the same effective stress level it would receive at working load.

Where tests are carried out in rock, blasting for rock excavation can seriously affect the rock to be tested. This effect can be minimized by using small charges, and by finishing the excavation by hand methods.

Figure 14 Types of bearing test equipment – Plate test equipment for 864 mm diameter

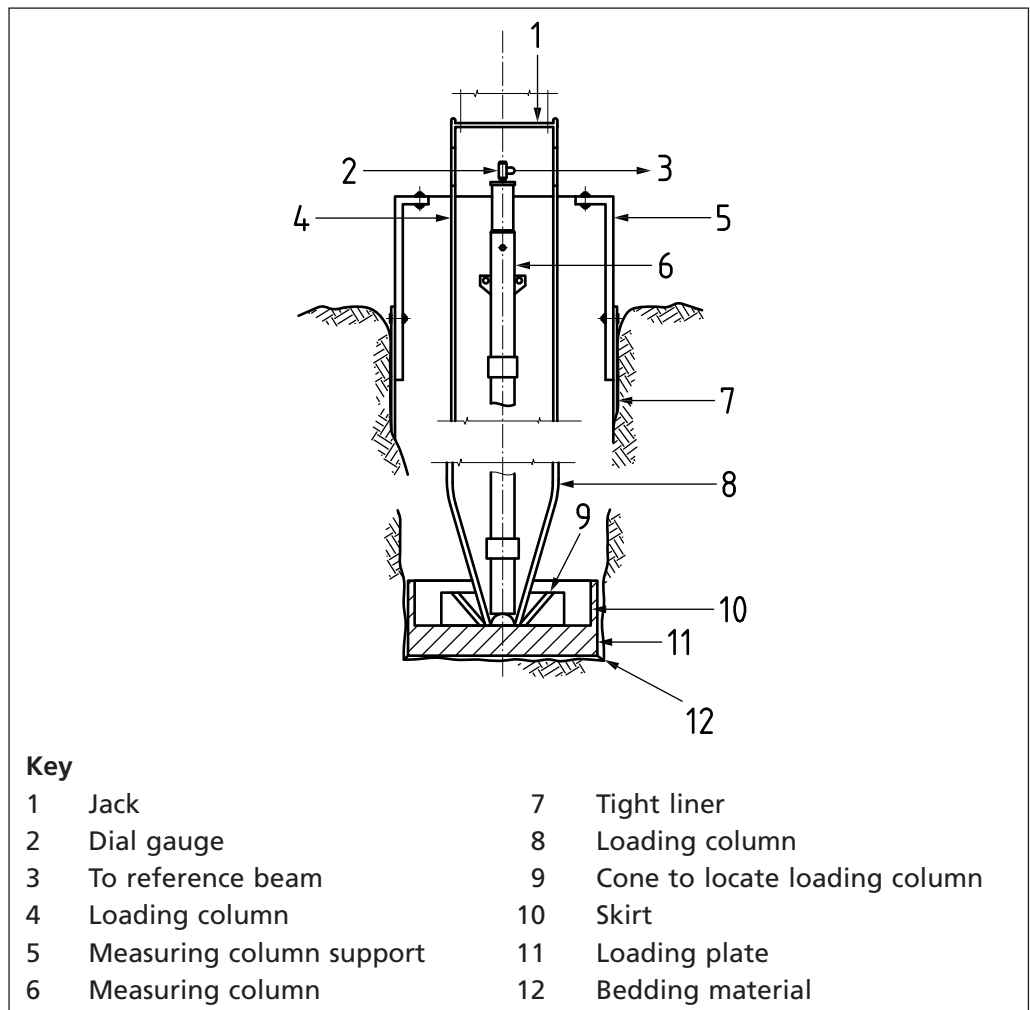
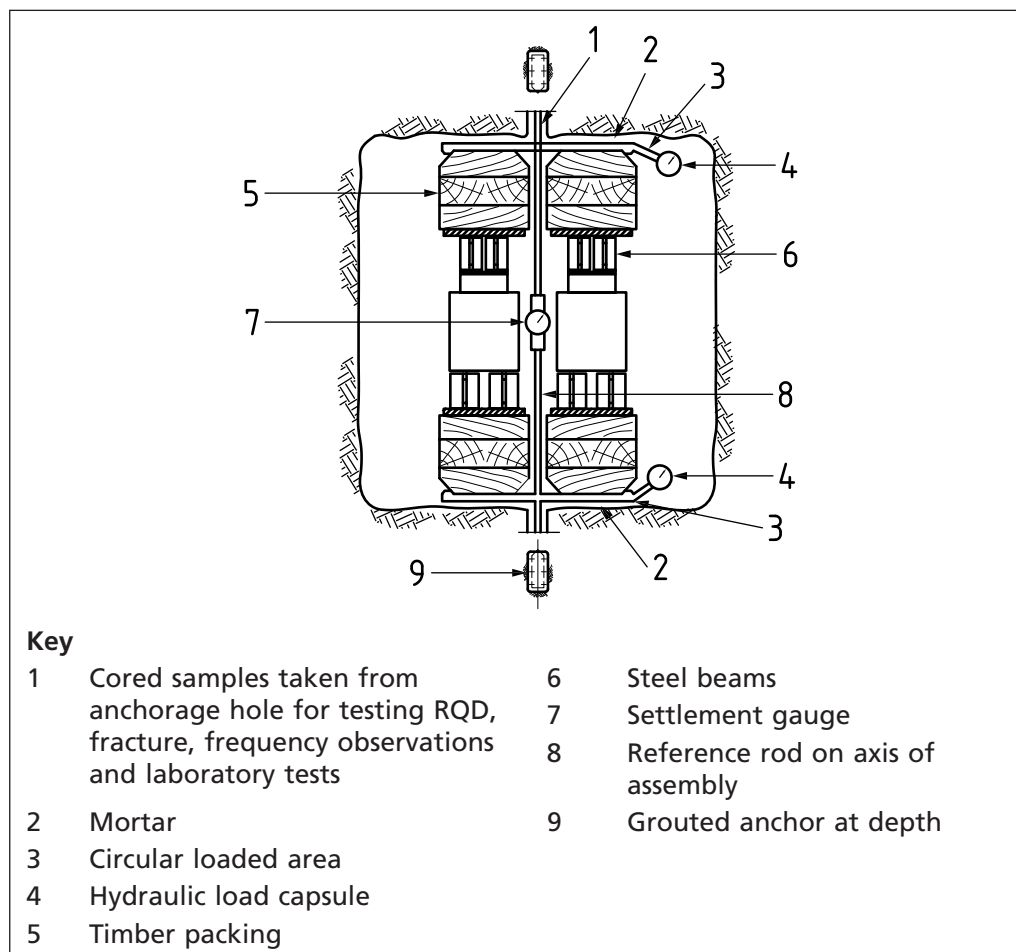


Figure 15 Types of bearing test equipment – Jacking in adit-type of loading equipment



#### 46.1.2 Limitations of the test

##### COMMENTARY ON 46.1.2

*The main limitations of the test are the possibility of ground disturbance in the course of the excavation to gain access to the test position, plus the significant expense of the excavation.*

*Unavoidable changes in the ground stresses are caused by an excavation, which can produce irreversible effects on the properties the test is intended to study. For example, in stiff, fissured, clay, some swelling and expansion of the clay inevitably occurs during the setting-up process, due to the opening of fissures and other discontinuities; this can considerably reduce the values of the deformation moduli (see Marsland, 1972 [103]). The moduli determined from plate tests are still more reliable, however, and often many times higher than those obtained from standard laboratory tests. In a project that involves a large excavation, e.g. a building with a deep and extensive basement, the excavation could cause disturbance to the ground beneath, with a consequent effect on the deformation characteristics. In such a case, it is necessary to allow for this unavoidable disturbance when interpreting the results of loading tests.*

*When carrying out the test below the prevailing ground water table, the seepage forces associated with dewatering might affect the properties to be measured. This effect is most severe for tests carried out at significant depths below the water table in soils and weaker rocks. It might, therefore, be necessary to lower the water table by a system of wells set outside and below the test position.*

The test is sometimes used to measure the ultimate bearing capacity. In cases where settlements and elastic deformation characteristics of the ground need to be determined, as in rock foundations, care should be taken to work at stresses that are relevant. The observation of deformation, particularly at low stress levels, requires the utmost care in surface preparation and setting-up to achieve meaningful results. The errors that can be introduced by sample disturbance and inaccuracies of measurement can often be similar in size to the data sought or indeed larger.

The effect of sample disturbance can be reduced, to some extent, by carrying out preliminary cycles of loading and unloading. The maximum load in these cycles should not exceed the intended load. The rate of loading should be sufficiently rapid to prevent any significant consolidation or creep.

*NOTE* After two or three cycles, the stress/settlement graph tends to become repeatable, and the test can then be extended to the main testing programme. The data from the preliminary load-cycles gives an indication of the effect of the sampling disturbance. The undrained deformation moduli, as measured after preliminary load-cycling, are normally a more reliable indication of the true properties of the undisturbed ground. Alternatively, displacement measuring systems can be installed in the ground beneath the plate, thus eliminating the effects of shallow disturbance (see Marsland and Eason, 1973 [104] and Powell et al., 1989 [101]).

### 46.1.3 Interpretation of results

The correct interpretation of the behaviour of the mass of ground should be made with a careful examination of the results, not only of the loading tests, but also of other data pertaining to the ground.

*NOTE* Depending on the objects under investigation, such data might include the geological structure, the nature and distribution of discontinuities, lithology and the variability of the ground.

Several deformation moduli can be obtained from these tests, depending on the method used and the application. The results reflect the effects of the width and frequency of the discontinuities, and give an indication of the mass material behaviour under loading. The stress level at which these parameters should be examined depends on the working stress levels. In the case of tests on rock in adits, it might be necessary to consider the in-situ stresses in the test sample.

The moduli to be used for design purposes should be those relating to the ground, both at the time of construction and after it has been affected by the construction procedures, e.g. a deep excavation might affect the deformation moduli of a soil, and blasting might affect the properties of a rock. Sometimes, the effect of a construction procedure might be sufficiently severe to justify the examination of alternative methods of construction.

On completion of the testing, full identification of the material (see Section 6) beneath the loaded area should be carried out by sampling and testing in the laboratory (see Section 3 and Section 5). In many cases, results obtained from these tests assist in extrapolating the test results to other areas on the site.

## 46.2 Plate tests

### 46.2.1 General

The plate load test is probably the most common vertical bearing test in use. Plates tests should be used to determine the stiffness and strength of the ground; they are also used for quality control of fills, etc. Test procedures should be carried out in accordance with BS 1377-9:1990, 4.1. They can be performed as surface tests either at ground surface or in pits and also at the base of boreholes.



The test comprises applying a load to a square or circular plate while monitoring the movement or penetration of the plate into the ground. Loading can be either using increments of load which are maintained for specified periods of time or until movement becomes minimal or by applying load so that the plate penetrates into the ground at a known speed/rate of penetration. The rate of application of the load determines if the test is taking place under undrained or drained conditions. The size of the plate used should be appropriate for the scale of features controlling the ground behaviour. Undertaking plate load tests in boreholes has specific problems.

Where, for reasons of economy, the test is conducted in a small diameter borehole, the cleaning of the bottom and the bedding of the plate should be done from the surface, and it is, therefore, very difficult to be certain that the plate is not resting on disturbed material. This limits the value of the results. Care should be taken to ensure that the plate movements are measured directly and that the effects of compression of the load column are eliminated. The strain distribution beneath the plate can be measured using an extensometer array (see Marsland and Eason, 1973 [104]).

The techniques for tests in large and small diameter boreholes differ in some respects mainly related to ability to clean and prepare the base of the borehole and is discussed further below. The diameter of the plate used should, so far as practicable, be equal of that of the borehole, provided that care is taken to eliminate cohesion or friction on the side of the plate.

*NOTE* Where the diameter of the plate is significantly less than that of the borehole, the results of the test become difficult to interpret. At a hole-diameter to plate-diameter ratio greater than about 3:2, the parameters being measured are those pertaining to a load at a free surface and not at depth under confined conditions, which are usually the conditions of interest.

## 46.2.2 Limitations

### COMMENTARY ON 46.2.2

*For the general limitations of the vertical load test, see 46.1.2. They apply similarly to the borehole test. Additionally, in the bottom of a borehole that is too small to allow hand preparation of the test surface, it is more difficult to achieve a satisfactory bedding of the loading plate on the test surface and, therefore, values obtained for the deformation parameters might be of limited significance.*

Casing should be used to support the sides of the borehole and to seal off water seepage from strata that are above the test elevation as necessary. When the test is to be carried out below the prevailing water table, dewatering by pumping or baling from within the borehole might cause seepage, which disturbs the ground and adversely affects its deformation characteristics, leading to a need for external dewatering.

If the test is undertaken only for measuring the strength parameters, disturbance due to groundwater seepage might be a less significant factor and the borehole could be emptied, if this is possible, while the plate is being installed. The water should be allowed to return to its normal rest level before the test is commenced. Alternatively, the plate can be installed under water, although it might not then be possible to set the plate sufficiently accurately for the deformation characteristics to be measured.

In small diameter boreholes the cleaning should be carried out by means of a suitable auger or hinged bucket operated at the end of a drill rod assembly. A layer of neat cement mortar should then be placed at the bottom of the borehole by means of a tremie or bottom opening bucket, and the plate lowered down the hole and lightly pressed on to the surface of the mortar. Plaster and resins may also be used for bedding.

Surface plate loads tests should be used to assess the performance of fills and compacted materials.

The test should be used to determine the strength and deformation characteristics of the mass ground. It may also sometimes be used to establish the working load of piles.

In small diameter boreholes the deformation characteristics obtained can often be of limited value owing to doubts about the elimination of ground disturbance and errors resulting from unsatisfactory bedding of the plate, although satisfactory unload/reload parameters can be obtained. The main use of the test is for measuring the strength characteristics of those cohesive soils in which undisturbed samples cannot be obtained, e.g. some gravelly clays and weaker rocks. The plate diameter should be large in relation to the structure of the ground.

*NOTE* Plate load tests are also be used as an indicator of CBR values in fills.

### 46.2.3 Long-term load tests

#### COMMENTARY ON 46.2.3

*The long-term settlement of fills is usually of much greater significance to the satisfactory functioning of structures built on the site than the movements that occur during construction. A variation of the bearing test can be used and is known as the long term maintained test. This test usually consists on casting a concrete slab on the surface of the fill and loaded by a deadweight which can be applied either by a skip or skips filled with sand or other suitable material (often referred to as the BRE skip test) or simply kentledge. The settlement of the pad is observed with time and referenced to a stable datum remote from the test.*

A long-term maintained load test should be carried out in accordance with BS 1377-9:1990, 4.2.

*NOTE* The actual period over which the test is carried out is inevitably a compromise between the theoretically desirable requirement of a period comparable with the life of the structure and the practical requirement of early development of the site. A month would seem to be a minimum for the test and it would be highly desirable for tests to be carried out over periods of 3 to 6 months, whenever possible.

### 46.3 Lateral and inclined loading tests

Lateral and inclined loading tests, which are essentially the same test procedures as vertical loading tests, should be carried out and analysed in a comparable way. Particular characteristics of the ground should be investigated by loading tests at a preferred orientation. These should be carried out in rock for investigations concerning tunnels and underground excavations.

*NOTE* A simple lateral loading test, using an hydraulic jack between the opposite sides of a trial pit, forms a very convenient means of measuring in situ the shear strength of soils. It is often used in soils that are not suitable for undisturbed sampling, e.g. clays containing gravel and cobbles (and boulders).

### 46.4 In-situ California bearing ratio (CBR) test

#### 46.4.1 General

The California bearing ratio (CBR) is a penetration test for evaluation of the mechanical strength of road subgrades and base courses. The test should be performed in accordance with BS 1377-9:1990, 4.3.

*NOTE 1* The test is performed by measuring the pressure required to penetrate a soil sample with a plunger of standard area. The measured pressure is then divided by the pressure required to achieve an equal penetration on a standard crushed rock material. The CBR test is fully described in BS 1377-4.

*NOTE 2 The CBR method of flexible pavement design is essentially an empirical method in which design curves are used to estimate pavement thickness appropriate to the CBR of the soil. There is no unique CBR of a soil and the value obtained in any test depends very much on the manner in which the test is conducted. The design curves are usually based on one carefully specified method of measuring the CBR, which is usually a laboratory method. The parameter required for the design of flexible pavements is the CBR attained by the soil at formation level after all necessary compaction has been carried out, the pavement has been laid, and sufficient time has been allowed to elapse for equilibrium water content to become established.*

Before embarking on in-situ CBR tests, careful thought should be given to how relevant these are to the design method to be used and whether the condition of equilibrium water content is likely to pertain.

#### 46.4.2 Limitations and uses of the test

##### COMMENTARY ON 46.4.2

*The CBR test is unsuitable for any soil containing particles of longest dimension greater than 20 mm, because the seating of the plunger on a large stone can lead to an unrepresentative result. The test with sands tends to give results much lower than the laboratory tests on which the design charts are based. The test is most suited to clay soils, subject always to the soil under test being at equilibrium water content. The water content at a depth of 1 m to 2 m below ground surface, where the soil is normally unaffected by seasonal changes in water content, often gives a good indication of the equilibrium water content, provided that there is no change of strata. An alternative is to carry out the test directly beneath an existing pavement that has identical soil conditions to those of the proposed construction; this method has been used with some success for the design of airfield pavements. In-situ CBR tests have sometimes been carried out in conjunction with in-situ density and water content tests and then linked with laboratory compaction tests. A judicious study of all the resulting data leads to a reasonable design parameter on suitable soils. Attempts have sometimes been made to use the test as a means of controlling the compaction of fill or natural formations, but they have not usually been successful and the procedure is not recommended.*

The CBR test should be used primarily to empirically determine the required thicknesses of flexible pavements. It should normally be performed on remoulded (compacted) specimens, although they might be conducted on undisturbed soils or on soils in the field.

#### 46.4.3 CBR from plate load tests

##### COMMENTARY ON 46.4.3

*Surface plate load tests are often specified for assessing CBR values for fills and sub-bases. The test is a specific application of the surface plate load test. The specification for this test seems to vary around the world but consists of incremental maintained loading of a 750 mm diameter plate. Increments are maintained until all movement has stopped or until a specified creep rate is attained in fine grained soils. A series of increments (between 4 and 7) are applied till a specified settlement is exceeded or a specified load reached (in the UK 1.25 mm to be exceeded by one increment, in the US 0.1 inch or 2.54 mm). From the test results a modulus of subgrade reaction is calculated as the slope of the load settlement curve from zero to 1.25 mm displacement. If smaller plates are used correction factors are applied. The CBR value is calculated from various correlations that are available.*

The correlations and test methods used should be compatible. The actual test method used and the correlations used should be reported in the Ground Investigation report.

## 46.5 Deflectometer test

### COMMENTARY ON 46.5

*The deflectometer test or falling weight deflectometer (FWD) is a testing device used to evaluate the physical properties of pavement. FWD data is primarily used to estimate pavement structural capacity for use in (but is not limited to) highways, local roads, airport pavements, and railway tracks. The machine is usually contained within a trailer that can be either towed to a location by another vehicle or, when used on railway tracks, placed on a hand trolley and pushed to the location.*

*The FWD is designed to impart a load pulse to the pavement surface which simulates the load produced by a rolling vehicle wheel. The load is produced by dropping a large weight onto a circular load plate – typically 300 mm diameter. A load cell mounted on top of the load plate measures the load imparted to the pavement surface. The load plate can be solid or segmented. The advantage of a segmented load plate is that it adopts to the shape of the pavement, giving an even distribution of the load on uneven surfaces.*

*Deflection sensors (geophones; force-balance seismometers) mounted radially from the centre of the load plate measure the deformation of the pavement in response to the load. Some typical offsets are 0 mm, 200 mm, 300 mm, 450 mm, 600 mm, 900 mm, 1 200 mm, 1 500 mm. The deflections measured at these sensors are termed D0, D200, D300, etc.*

*FWD data is most often used to calculate stiffness-related parameters of a pavement structure. This process is computationally intensive although quick on modern computers. It can give quite misleading results and requires an experienced analyst. Instead, many analysts use simplified methods to calculate related parameters that are empirical in nature.*

*A light weight deflectometer (LWD) is a portable falling weight deflectometer. It is used primarily to test inset base and subgrade moduli during construction. Light weight deflectometers (LWD) are quicker than the isotope measuring method and requires no reference measurements. The equipment can be operated by one operator, allowing for the analysis of collected data and printing out of data files on site.*

*A heavy weight deflectometer (HWD) is a falling weight deflectometer that uses higher loads, used primarily for testing airport pavements.*

*A rolling weight deflectometer (RWD) is a deflectometer that can gather data at a much higher speed (as high as 55 mph) than the FWD. It is a specially designed tractor-trailer with laser measuring devices mounted on a beam under the trailer. Another advantage of the RWD over the FWD is that it can gather continuous deflection data as opposed to discrete deflection data collected by the FWD. RWD development has been carried out independently by Applied Research Associates (ARA) since 2005 and KUAB Sweden since 1991.*

The deflectometer test should be carried out and the data processed following the guidance given by the Highways Agency or in the manufacturer's literature. The correlations adopted should be appropriate to the method used for the test but even so the results should be treated with caution.

## 47 In-situ shear tests

### 47.1 General principles of the direct shear test

The direct shear test should be designed to measure the peak shear strength of the in-situ material as a function of the stress normal to the sheared plane (see *ISRM suggested method* [105]).

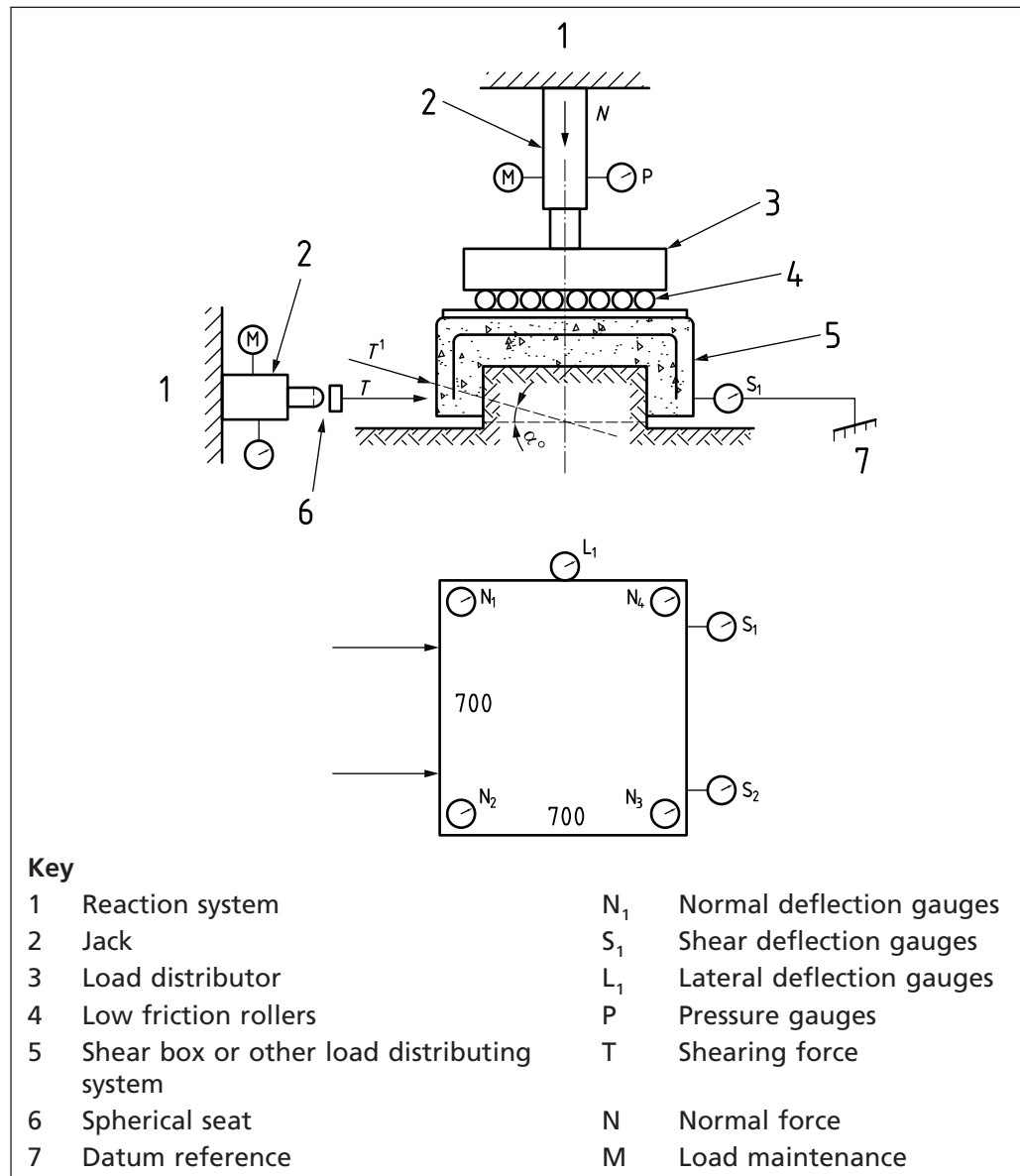
*NOTE 1 More than one test is normally required to obtain a sensible design value. The measurement of residual shear strength presents major practical problems in arranging for a sufficiently long travel, but a useful indication of residual strength can be obtained by continuing the test to the limits of travel of the apparatus. In certain applications, the test may be designed to establish the strength of the interface between concrete and rock or soil.*

For this test, a sample of ground, prepared and tested in situ, should be subjected to direct shear, using a stress system similar to that of the laboratory shear box tests (see Figure 16). The samples should be selected to include one or more discontinuities, if this is what is to be tested. The orientation of the discontinuities should be selected as relevant to the stress conditions being considered. The maximum sample size is often limited by practical considerations of loading and accessibility.

The orientation of the sample and the forces applied to it should be governed by the direction of the forces that become effective during and on completion of the works, but should be modified to take account of the orientation of significant discontinuities. In many cases, however, to facilitate the setting-up of the test, the sample should be prepared with the shear plane horizontal. The normal and shearing stresses should be imposed as forces applied normally and along the shear plane. However, an inclined shear force passing through the centre of the shear plane may be used, as this tends to produce a more uniform distribution of stress on the shear surface (see *ISRM suggested method* [105]).

*NOTE 2 Field shear testing of intact soil might be necessary sometimes. Although it is theoretically possible to carry these out in the consolidated, unconsolidated drained or undrained state, in practice it is not usually possible to prevent some drainage. Such testing might be used on weaker rocks.*

Figure 16 Equipment layout for shear and sliding friction test on rock or soil samples



## 47.2 Limitations of in-situ shear test

### 47.2.1 General

#### COMMENTARY ON 47.2.1

The in-situ general test in rock is described fully in the ISRM suggested method [105]. In-situ shear tests in soil are described in Marsland, 1988 [106].

Samples are normally prepared at the bottom of pits or trenches in soil. Adits are more common for rock testing. The excavation permits access to the material at the zone of interest and, in many cases, provides a suitable means of setting up the reaction for the applied forces.

As a rough guide, the sample dimension should be at least ten times that of the largest particle; in rock, the sample size should reflect the roughness of the rock discontinuity being tested. For stronger rocks, the sample can be rendered with suitably strong cement and reinforced concrete to ensure adequate load distribution. The equipment should be of robust construction. Samples between 600 mm<sup>2</sup> and 1 500 mm<sup>2</sup> have been used for testing soil and weak rocks. Larger samples might be required in ground containing boulders or in compacted fill material.

Great care should be exercised in preserving the environmental conditions when carrying out the excavation. Excavation techniques that give rise to crumbling, fracturing or excessive dynamic shock loading, which would affect the discontinuities in the sample test area, should be avoided. Hand sawing, cutting and diamond drilling should be used to prepare and trim the sample. Adequate protection from the weather should be provided. Final exposure and trimming of the sample to fit the loading frame and the testing should all be completed with the minimum of delay to avoid possible significant changes in the moisture and stress conditions of the sample. Where tests are carried out below the water table, precautions should be taken to avoid the effects of water pressure and seepage.

Where it is intended to test one discontinuity only, care should be taken to avoid disturbance to the surface of the discontinuity and to prepare the sample so that the forces are applied in the plane of the discontinuity in the manner intended. The spatial orientation of the discontinuity should be defined by its dip and strike.

Where drained conditions are required, suitable drainage layers should be inserted around the sample and on the loaded upper surface.

#### 47.2.2 Test arrangement

A typical test layout for determining the peak shear strength is shown in Figure 16. In addition, a porous top plate or other suitable medium should be used to distribute the load where drained conditions are required. The alignment of the force should be maintained during the test.

If a constant normal load is required for this type of test, a suitable reduction should be made from the applied normal load during testing, to compensate for the increase in the vertical component with increasing shear force. The shear force application should be developed by similar means to the normal loading. In both cases, care should be taken to ensure that the ground reaction does not extend to the sample. The reaction system can frequently be provided by the excavation sidewalls. In certain cases, it might be necessary to provide the shear force by traction on a system anchored by piles or anchored cable. Sufficient travel should be provided to run the complete test.

#### 47.2.3 Method of carrying out the test

The forces used for the testing programme should be in the range of the working stresses to be applied by the structure. The peak force and an estimate of the residual direct shear strengths should also be determined to establish a factor of safety.

When testing a single fissure or joint, care should be taken to establish the initial slope of the fitted line at the lower normal stresses.

*NOTE* Sometimes, low values occur at lower normal stresses until the asperities on the joint surface interlock. Photographs of the shear surface form a useful record.

Extrapolation of results obtained on single joints should not be attempted without due confirmation that the joint surface tested is representative of the planeness and roughness of the joints in the mass (see Section 6). If not, appropriate calculations for extrapolation can be used (see Patton, 1966 [107], Ladanyi and Archambault, 1970 [108] and Barton, 1971 [109]).

Where failure occurs in a plane that dips at an angle to the applied shearing force, the analysis given in Bishop and Little, 1967 [110] may be used.

On completion of the test, full identification of the material and that immediately surrounding the sample should be carried out by sampling, visual examination and laboratory testing. Tests on relatively small samples of single joints might give useful values of angle of shearing resistance, but the cohesion parameter tends to be size dependent.

## 48 Geohydraulic testing

### COMMENTARY ON CLAUSE 48

*It is necessary to understand the groundwater regime within which a project is to be constructed for a number of reasons. These include the correct evaluation of the soil parameters for the design of the structure and its foundations, the design and implementation of temporary works to enable construction of the works and the protection of the environment, in particular groundwater as a valuable and sustainable resource during the construction and life time of the works.*

*Intrinsic permeability is usually measured with respect to air and is independent of the fluid.*

*Permeability, as used in this British Standard, is strictly the hydraulic conductivity, a measure of the rate of water flow.*

The guidance given in BS EN 1997-2:2007, 2.1.4 and BS EN ISO 22282-1 should be followed. In order to meet these requirements, tests should be carried out in the field to determine the properties of the ground, in particular the permeability of the soil and the transmissivity and storage coefficients for aquifers.

In-situ permeability testing should be carried out in accordance with the various parts of BS EN ISO 22282. It is important that the correct test is carried out as the tests are often limited to a particular situation and in particular to a limited range of permeabilities.

*NOTE 1 Before carrying out any tests, it is important to identify the aquifer and understand whether it is confined or unconfined. The determination of in-situ permeability by tests in boreholes involves the application of an hydraulic pressure in the borehole different from that in the ground, and the measurement of the rate of flow due to this difference. The pressure in the borehole may be increased by introducing water into it, which is commonly called a "falling head" or "inflow test", or it may be decreased by pumping water out of it in a "rising head" or "outflow test". The pressure may be held constant during a test (constant head test) or it may be allowed to vary (a variable head test). The technique is applicable only to the measurement of permeability of soils below groundwater level. The measurement of the permeability of unsaturated or partially saturated zones is extremely difficult. A variety of tests is available, ranging from the simple, which can nevertheless be used to investigate complex situations, to the sophisticated; the interpretation of the data is crucial. It is important to establish the normal fluctuations within the aquifer.*

*NOTE 2 For most types of ground, field permeability tests yield more reliable data than those carried out in the laboratory, because a larger (although still modest) volume of material is tested, and because the ground is tested in situ, thereby avoiding the disturbance associated with sampling.*

To achieve representative test results, care should be taken in the choice of appropriate drilling methods and careful drilling techniques used to avoid disturbing the ground to be tested. In coarse soils, the ground can be loosened below the bottom of the borehole; in laminated ground, a skin of remoulded mixed material can be formed on the walls of the borehole, thus blocking the more permeable laminations; in fractured rock, the fractures might be blocked by the drilling debris.



The selection of the test method should also take account of the likely permeability to be measured. With soils of high permeability, i.e. greater than about  $10^{-3}$  m/s, flow rates are likely to be large and head losses at entry or exit and in the borehole might be high. In this case, the use of field pumping tests, where the pressure distribution can be measured by piezometers on radial lines away from the borehole, should be evaluated. In lower permeability soils and in rock down to about  $10^{-7}$  m/s, the test should be carried out using a standpipe or piezometer which is sealed within the test length using grout (see Hvorslev, 1951 [111]). In ground of low permeability, the flow rate might be very small, and measurement can be subject to error owing to changes in temperature of the measuring apparatus. The permeability in soils is influenced by the effective stress and the stress history. This should be taken into account in the test regime and in the analysis of results.

*NOTE 3 Constant head tests might give more accurate results than variable head tests; but on the other hand variable head tests are simpler to perform, allow a number of different methods of analysis and can indicate other effects.*

The water pressure used in testing should be less than that which disrupts the ground by hydraulic fracturing. It has been shown that serious errors can be introduced if excessive water pressures are used.

*NOTE 4 When the test is carried out within a borehole using the drill casing, the lower limit of permeability that can be measured reliably is determined by the watertightness of the casing joints and by the success achieved in sealing the casing into the ground.*

*NOTE 5 There might be significant differences between the results of inflow tests, in which effective stress is reduced, and the results of outflow tests, in which it is increased. The permeability of soil around the borehole can also be influenced by changes in its stress history owing to installation of the borehole and any previous permeability tests performed on it.*

Permeability tests should be carried out by suitably experienced persons; execution of the borehole tests requires expertise, and small faults in technique can lead to errors of up to one hundred times the actual value. Even with considerable care, an individual test result is often accurate to one significant figure only. Accuracy can be improved by analyzing the results of a series of tests. In many types of ground, however, particularly stratified soil or fractured rock, there might be very wide variations in permeability, and the important measure of the permeability of the mass of ground may be determined by a relatively thin stratum of high permeability or a major fracture.

Considerable care should be exercised in interpreting the test data. Where a reliable result is required, the programme of borehole permeability tests is normally followed by a full-scale pumping test.

*NOTE 6 Many effects of the geohydraulic tests are not only influenced by the ground itself, but stem from the testing procedure. Historically, the water pressure test was evaluated based on the assumption that the stationary behaviour was achieved. Recent advances in geohydraulics have shown that transient phenomena are often present. BS EN ISO 22282-3 attempts to address the limitations of certain testing procedures without restricting the required equipment too stringently. The water pressure test can be carried out in a borehole of any orientation and diameter. The test section can be located either below or above the groundwater level.*

For open piezometer systems, the guidance in BS EN ISO 22282-2 should be followed.

*NOTE 7 BS EN ISO 22282-2 specifies requirements for the determination of the local permeability in soils and rocks below and above groundwater level in an open hole by water permeability. Constant flow rate test method is suitable for  $k$ -value greater than  $10^{-6}$  m/s; the variable head test method is suitable for  $k$ -value between  $10^{-6}$  m/s and  $10^{-9}$  m/s; the constant head test method is suitable for  $k$ -value between  $10^{-4}$  m/s and  $10^{-7}$  m/s.*

Water pressures tests (WPT) in boreholes drilled into rock (also known as "Packer tests") should be carried out in accordance with BS EN ISO 22282-3.

*NOTE 8 The tests are used to investigate the following:*

- *hydraulic properties of the rock mass, which are mainly governed by discontinuities;*
- *absorption capacity of the rock mass;*
- *tightness of the rock mass;*
- *effectiveness of grouting; and*
- *geomechanical behaviour, e.g. hydrofracturing, hydrojacking.*

When undertaking pumping tests as part of geotechnical investigation, BS EN ISO 22282-4 should be used. It applies when tests are performed on aquifers whose permeability is such that pumping from a well can create a lowering of the piezometric head within hours or days depending on the ground conditions and the purpose. It covers pumping tests carried out in soils and rock. It should be used for evaluating the hydrodynamic parameters of an aquifer and well parameters, such as:

- permeability of the aquifer;
- radius of influence of pumping;
- pumping rate of a well;
- response of drawdown in an aquifer during pumping;
- skin effect;
- well storage; and
- response of recovery in an aquifer after pumping.

Pumping tests should be used to determine the transmissivity,  $T$ , and the storage coefficient,  $S$ .

*NOTE 9 A pumping test consists in principle of drawing down the piezometric surface of the groundwater by pumping from a well (the test well) and measuring the pumped discharge and the water level in the test well and piezometers, before, during and after pumping, as a function of time.*

When undertaking testing for the determination of the water permeability of an existing geological formation or of treated or compacted materials BS EN ISO 22282-5 should be used. The infiltrometer test is used to determine the infiltration capacity of the ground at the surface or shallow depth.

*NOTE 10 The infiltrometer test is a simple test for determining the permeability coefficient. The method can be applied using either steady-state or transient conditions, in saturated or unsaturated soils. Surface infiltration devices include single and double-ring infiltrometer designs of the open or closed type. The measurement devices and measurement procedures are adapted to different ranges of permeability. Open systems are adapted to permeability ranges from  $10^{-5}$  m/s to  $10^{-8}$  m/s and closed systems for permeability lower than  $10^{-8}$  m/s. This test is not commonly used in the UK.*

When undertaking testing on for closed system tests, described as "pressure pulse tests" but are also known as "transient" or "slug tests", BS EN ISO 22282-6 should be followed. (Neither of these test methods is used commonly in UK.)

Soakaway “infiltration” tests are often undertaken in connection with drainage design and should be carried out in accordance with *BRE Digest 365* [N3]. These tests are generally performed in pits or trenches and are specific to the design procedure in the BRE Digest. They are infiltration tests and should not be used to assess permeability.

The method of determination should give representative results for the proposed site of the soakaway or system. This is achieved by:

- Excavating a trial pit of sufficient size to represent a section of the design soakaway. The infiltration test requires a trial pit (or pits) located in the vicinity of the proposed soakaway. The depth should match the depth of the proposed soakaway, i.e. the total depth from the finished ground level should be equal to the depth to invert of the surface water drain (0.75 m – 1.5 m) plus the proposed operating depth of the soakaway
- Filling the pit three times in quick succession whilst monitoring the rate of seepage, to represent soil moisture conditions typical of the site when the soakaway becomes operative (only filling as high as the invert level).
- Examining site data to ensure that variations in soil conditions, areas of filled land, preferential underground seepage routes, variations in the level of groundwater, and any geotechnical and geological factors likely to affect the long-term percolation and stability of the area surrounding the soakaway have been assessed.
- Following the BRE Digest method fully.

Groundwater should not rise to the level of the base of the soakaway, during annual variations in the water table.

## 49 Large-scale field trials

### 49.1 General

Large-scale field trials should be carried out in such a manner that the ground is tested on a scale and under conditions comparable with those prevailing in the project under investigation. Such trials, however, are likely to be costly in terms of instrumentation, technical support for the co-ordination of the results and requirements of purpose-made equipment. Trials should include an appropriate range of investigation methods, tests and instruments as described in Sections 4, 5 and 7. Large-scale field trials are not standard tests, and should be designed to suit the individual requirements of the proposed works and the particular ground on which or within which these are to be performed.

*NOTE* On large projects, field trials can provide the necessary design parameters and valuable construction data on excavation, handling and placing, resulting in considerable savings and enhanced safety. Such methods and trials can usefully be extended to the construction stage and to monitoring the interrelated response of the ground and structure after completion under the working conditions.

### 49.2 Methods of instrumentation

#### COMMENTARY ON 49.2

*Numerous techniques are available to be used in ground investigations to monitor movements and strains, total stresses and pore water pressures associated with known or suspected ground behaviour. Such movements can result from construction processes, potential stability failures, tunnelling, subsidence and ground response in large scale field trials. The types, advantages, limitations and appropriateness of the various techniques are discussed in detail elsewhere.*

*Field instrumentation is technology-based, which advances rapidly. Accordingly, users of instrumentation are encouraged to follow the developments by browsing manufacturers' websites and using other online sources of information (e.g. [www.geotechnicalnews.com](http://www.geotechnicalnews.com)).*

Ground movements are normally associated with stress redistribution and pore pressure changes which are characteristic of the particular ground and should be measured in terms of the displacement of points, which can be positioned on the surface of the ground or within the ground mass. The displacement of a point should be referred to a stable reference position, and sufficient measurements taken to define movement in three dimensions if this is required. The relative movement between adjacent points can be used to obtain strain.

Surface movements should be measured using one of the following:

- precise levelling;
- surveying;
- total stations (automatic or manually operated)
- photogrammetric methods; or
- global positioning systems (GPS).

*NOTE 1 An accuracy of  $\pm 0.5$  mm can be achieved with precise levelling and  $\pm 3$  ppm for distance measurements over 2 000 m can be achieved using EDM (electronic distance measurement) instruments. Manually operated total stations can typically deliver an accuracy of  $\pm 2.5$  mm in X, Y and Z coordinates of a monitoring point if the sighting distance is less than 75 m. Automatic (robotic) total stations mounted on fixed platforms that don't move can deliver accuracies as good as  $\pm 1.0$  mm if they are properly installed and maintained.*

Care should be taken to position reference points away from the effects of movements due to load and water changes. Due account should be made for atmospheric disturbances and care taken to avoid positioning instruments in locations that are adversely affected by wind, vibrations and construction activities.

Internal movements or displacements and stresses should be measured in boreholes or by direct placement of instruments within fill using the following techniques.

- a) Extensometers and settlement gauges:
  - magnet;
  - plate; and
  - rod.
- b) Lateral or horizontal movements measured by:
  - inclinometers;
  - tilt sensors
  - inverted pendulums; and
  - magnet plate gauges.
- c) Total stress monitored using:
  - hydraulic cells;
  - vibrating-wire cells;
  - push-in type cells; and
  - interface pressure measurements.

The techniques for the measurement of pore pressure response are covered in Clause 52.

*NOTE 2 Many types of automatic data-logging are available. It is essential that great care is taken when maintaining and assessing the performance of the instruments and the quality of the data recorded.*

*NOTE 3 For the design of an instrumentation programme, see Section 8.*

### 49.3 Trial embankments and excavations

#### COMMENTARY ON 49.3

*The construction of trial embankments can serve a threefold purpose: the quality and compaction characteristics of available borrow material can be determined on the field scale and compared with laboratory test results; the characteristics and performance of placing and compacting equipment can be investigated; and the strength and settlement characteristics of the ground on which the embankment is placed can be examined. A trial embankment can be constructed in such a way that, where failure is of no consequence, it can be induced deliberately, either in the embankment alone or in the embankment and the foundations. Such failures sometimes occur in an unexpected manner, and precautions ought to be taken by the engineer to ensure that no injury to persons or unexpected damage is caused; even so, some installed instrumentation might be destroyed. The value of such a failure is that back analysis (see 49.5) can be used to check strength parameters.*

Compaction trials can include experiments using differing borrow pit materials, layer thickness, amounts of watering and amounts of work performed in compaction. Measurements should be taken of in-situ density and water content and comparisons made both with laboratory compaction tests to obtain a specification standard, and with in-situ borrow pit densities, so that the degree of bulking or volume reduction can be estimated for given quantities (see BS 6031). Trials of equipment can also be undertaken. Care should be taken not to vary too many factors at the same time, otherwise the effects of variation cannot be estimated.

*NOTE Trial excavations yield information on the material excavated and the performance of excavating equipment, and they also permit more detailed examination of the ground than is possible from borehole samples. Excavations can sometimes be used to test the short-term stability of excavated slopes. Trial excavations can be constructed deliberately to fail. However, failure in excavation, especially if deep, is correspondingly more dangerous than failure of fills, and increased vigilance is needed. Trial excavations also enable the response of the ground and groundwater to excavation to be measured.*

Adequate instrumentation to trial embankments or excavations should be used, together with continuous observation (see 33.2), if the maximum information is to be gained. The scale of trial embankments or excavations should be carefully evaluated. The more closely the size of the trial approaches that of the actual works, the more directly applicable are the results obtained from the trial.

### 49.4 Construction trials

#### COMMENTARY ON 49.4

*In many projects, considerable value can be derived from trials carried out before the commencement of the permanent works. Such trials permit the evaluation of the procedures to be adopted and the effectiveness of the various expedients. As with all large-scale testing, a prior knowledge of the characteristics of the ground is essential. The results of the trial give an assessment of the properties of the ground and often enable the results to be correlated with those obtained from routine ground investigation methods.*

A wide range of expedients should be tested in trials. Examples include: construction methods, such as pile tests; ground anchor tests; compaction tests for earthworks, experimental shafts and adits for tunnels; and construction methods such as grouting trials, trial blasts for explosives and dewatering trials.

#### **49.5 Back analysis of full-scale performance**

##### *COMMENTARY ON 49.5*

*Natural or man-made conditions on a site sometimes produce phenomena that can be used to assess parameters which are otherwise difficult to assess, or that can be used to check the validity of parameters measured in the laboratory. Examples of such phenomena are slope failure and settlement of a structure. It might be possible, starting from the observed phenomena, to perform a back analysis and, in the case of a slope failure, to arrive at shear strength parameters that fit the observed facts.*

Back analysis of settlements is also possible, but care should be taken in assessing actual loadings and the times when they have taken place. For a back analysis to be effective, it should be accompanied by a full investigation to determine the ground and groundwater conditions. The development of finite element techniques has greatly improved the ability to back analyse more complicated geotechnical structures.

## Section 8: Field instrumentation

### 50 General

#### COMMENTARY ON CLAUSE 50

*Numerous techniques are available to be used in ground investigations to monitor movements and strains, total stresses and pore water pressures associated with known or expected ground behaviour (see Section 7). Such behaviours can result from construction processes, potential stability failures, tunnelling, subsidence and ground response in large-scale field trials. The types, advantages, limitations and appropriateness of the various techniques are discussed in detail elsewhere (see Dunnicliff, 1988 [112], ICE, 1990 [113] and ICE, 2012 [114]). The principal types of instrumentation used in ground investigation are piezometers for measuring ground water pressures and inclinometers and extensometers for measuring ground movements. Other types of instrumentation are outlined in BS EN ISO 18674.*

Utilities should be identified before any intrusive work commences (see 19.2.4).

The design of an instrumentation programme, including the selection of instrument types, their location and their monitoring is a complex issue that requires experience and judgement; the geotechnical adviser should ensure that appropriate and skilled advice is obtained to guide this design. An instrumentation specialist should be used to install and read the instruments and possibly help interpret the results, where appropriate.

It should be taken into account that instruments might malfunction and give no measurements or, worse, give erroneous results, or that the installation of instrumentation could affect behaviour of the ground, particularly with respect to earth pressure measurements. The limitations of any instrumentation should be taken into account, particularly for long-term measurements.

*NOTE 1 Electrical instruments are more likely to fail than mechanical ones, which are simple and robust. All measurements, however, are usually discontinuous in space and time. Data from instrumentation is not comprehensive and might not record the most adverse circumstances.*

All instrumentation should be protected at the surface from the adverse effects of weather (including temporary flooding), construction activities and other potential damage, both accidental and deliberate. Electrical instruments and data loggers should be protected from power surges and lightning strikes using replaceable fuses.

When displacements are being measured, they should be referenced to a fixed or known point; in the case of downhole measurements, the fixed or known point can be at the bottom or the top of the borehole. If the bottom of the borehole is used, fixity should be confirmed by at least five sequential points showing no relative displacement. Measuring the position of the top of the borehole by surveying is also acceptable.

Following installation, an instrument should be allowed to stabilize and measurements should be taken at regular intervals to determine when the installation of the instrument has stabilized satisfactorily. The geotechnical adviser should advise on the required stability. When stability has been confirmed, a single "zero" measurement is taken; thereafter a series of "baseline" measurements are taken, the frequency of which should be provided by the geotechnical adviser and the purpose of which is to identify changes that occur due to causes other than those being investigated and to assign a reference measurement for subsequent monitoring.

*NOTE 2 BS EN ISO 18674-1 provides comprehensive guidance on this process.*

## 51 Planning a field monitoring programme

When planning a field monitoring programme it is as important to define the objectives as it is to choose the appropriate instrumentation. The following procedure for planning monitoring programmes using instrumentation should be adopted, and checked by the geotechnical adviser responsible for the instrumentation working with the designer (see Dunnicliff, 1988 [112]).

- Step 1: Define the project conditions;
- Step 2: Predict the mechanisms that control behaviour;
- Step 3: Define the geotechnical questions that need to be answered;
- Step 4: Define the purpose of the instrumentation;
- Step 5: Select the parameters to be monitored;
- Step 6: Predict the magnitudes of change;
- Step 7: Devise remedial action;
- Step 8: Assign tasks for design, construction and operation phases;
- Step 9: Select the instruments;
- Step 10: Select the instrumentation locations;
- Step 11: Plan recording of factors that might influence the measured data;
- Step 12: Establish procedures for ensuring correctness of the readings;
- Step 13: List the specific purpose of each instrument;
- Step 14: Prepare budget;
- Step 15: Prepare an instrumentation system design report;
- Step 16: Write instruments procurements specifications;
- Step 17: Plan the installation;
- Step 18: Plan regular calibration and maintenance;
- Step 19: Plan data collection, processing, presentation, interpretation, reporting and implementation;
- Step 20: Write specifications for field instrumentation services; and
- Step 21: Update budget.

*NOTE Further advice on the planning process is available in ICE, 2012 [114], ICE, 2011 [115] and BS EN ISO 18674.*

## 52 Groundwater measurements

### 52.1 General

Groundwater measurement installations and groundwater measurement methods should conform to BS EN ISO 22475-1:2006, Clause 9 and Clause 10 respectively.

### 52.2 Observation wells installed in boreholes and excavations

#### COMMENTARY ON 52.2

*Determination of the unconfined groundwater level can be made by observation in an open borehole or excavation. Water level observations in an open borehole or excavation are frequently not indicative of equilibrium conditions as discussed in 26.2 and a considerable period of time might be required for the water level to reach an equilibrium unless the ground is reasonably permeable.*



Observations of water level in an open borehole or excavation should be made at regular intervals until it is established that the water level has reached an equilibrium.

Where the time to reach an equilibrium is likely to be more than one day or there is a likelihood that the borehole or excavation could collapse, an observation well (sometimes called a simple standpipe) should be installed into the borehole or excavation. Observation wells usually comprise a perforated tube, often 50 mm diameter, but sometimes of the same construction as a standpipe piezometer (see 52.5). The perforated section should cover the zone of ground where the unconfined measurements are required. The annulus between the porous/perforated section (which might not be the whole length of the pipe) and the walls of the borehole should be filled with a granular filter material. When there is a possibility of fine particles (e.g. if 10% of the surrounding strata is finer than 2 mm) an inert geotextile material should be wrapped around the perforated section of the tube. The effects of using a screening material on the subsequent measurements (e.g. permeability) should be assessed. Grout should be used around unperforated sections of the well to prevent water entering the well from strata that are not being investigated.

If water samples are required to be taken from the well (see 26.4), it should be constructed from materials that do not react with the ground and that do not release or absorb contamination.

If gas samples are required, a rubber bung or tight fitting plastic cap with gas tap(s) should be fitted at the top of the tube. Wells intended for the monitoring and sampling of ground gases should be constructed in accordance with BS 8576 and BS 10175.

Observations in open boreholes and excavations (with or without a properly constructed observation well) should not be relied upon when the depth of the borehole or excavation spans more than one hydrogeological unit (e.g. where perched water is separated from a deeper aquifer by a lower permeability material). In such circumstances, observations should be made in separate observation wells, terminated and sealed to prevent the ingress of water from depths other than the depth of interest.

*NOTE 1 An alternative to the use of independent observation wells is to drill a larger diameter hole down to the bottom of the low permeability strata and construct an impermeable plug of suitable material and sufficient thickness (e.g. bentonite/cement grout with a thickness of at least 1 m). This could necessitate some preliminary trials to confirm that the selected material is effective. The plug is allowed to set before continuing the borehole by forming a smaller diameter hole. In this way a seal (to prevent the downward migration of contamination) is created. The borehole is grouted, as the casing is withdrawn in order to complete the seal.*

Following installation, and before the start of the monitoring programme, the observation or monitoring well should be fully "developed" to maximize the rate at which groundwater flows into the well from the surrounding strata. Various methods can be used to develop wells (see BS ISO 14686), although perhaps the most appropriate for monitoring wells is by "purging" (i.e. the water standing in the well is removed by bailing or pumping so as to induce replenishment with groundwater). This development should also settle the granular surround and ensure free flow of liquids through the well screen. The rate of pumping should be substantially greater than that proposed for subsequent purging or sampling.

Development should continue until the water is visibly clean and/or of constant quality (e.g. in terms of its electrical conductivity). This operation should be continued until three well volumes plus the volume of water added during drilling, frequently taken as five well volumes of water (see BS ISO 5667-3), have been purged. Adequate provision should be made for the disposal of contaminated water from monitoring wells resulting from well development and purging operations.

*NOTE 2 The use of cement/bentonite or similar materials in monitoring well construction can affect the water chemistry (e.g. pH). A sufficient equilibration period and the use of alternative materials minimize the likelihood of any such effects occurring.*

Once installed, sufficient time should be allowed to elapse after completion of the borehole for conditions to stabilize so that the unconfined groundwater level (and any subsequent variations with time) can be monitored. If samples of groundwater are required, at least 14 days should be allowed for an equilibrium to be reached, but when this is not possible the time allowed should be as long as practicable.

When all monitoring work has been completed and there is no further need for the observation well, it should be sealed by grouting, ensuring that the grouting is effective above and below the water table.

*NOTE 3 Further guidance on the decommissioning of boreholes can be found in the Environment Agency guidance document Decommissioning Redundant Boreholes and Wells [26].*

The level of water measured in a borehole with or without an observation well should not be used as an indication of a pore water pressure because the levels from which the water is entering the borehole are unlikely to be known. A piezometer should be used if the groundwater pressure is required.

### 52.3 Methods of measuring groundwater pressure

The selection of an open (unconfined) or closed (confined) system to undertake groundwater measurements should be based on the hydrogeological conditions at the location. Open systems rely on the measurement of a free unconfined groundwater surface (i.e. at atmospheric pressure), typically in an open pipe. In closed systems the water pressure in a confined section is measured, generally by an electrical transducer or less commonly an hydraulic or pneumatic piezometer.

### 52.4 Response time

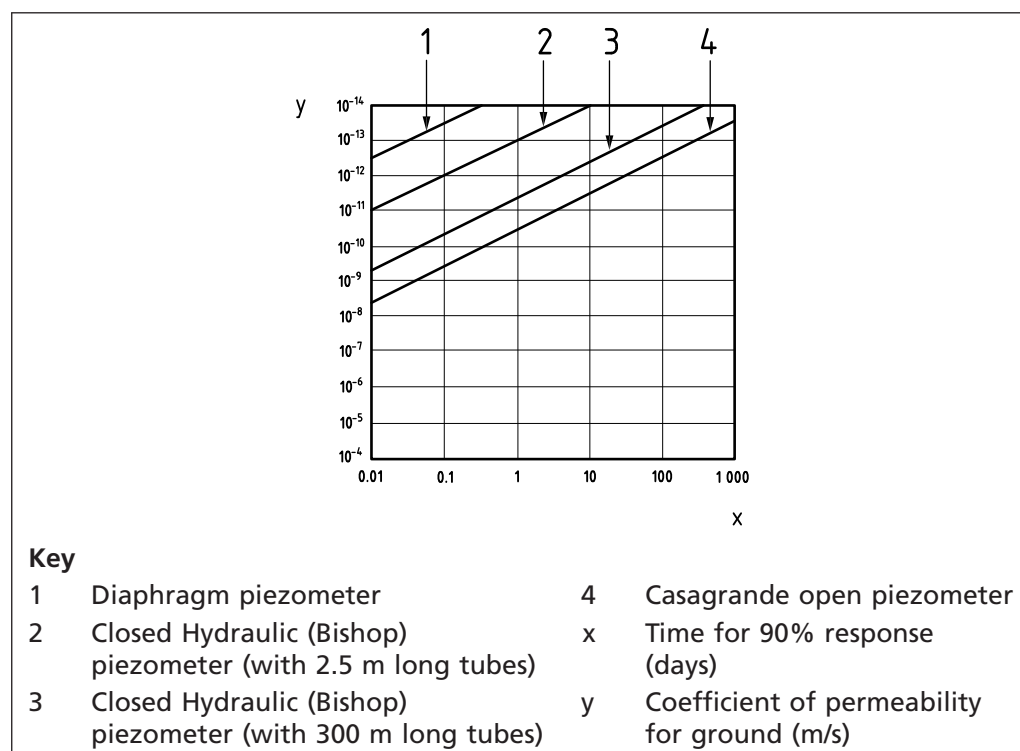
#### COMMENTARY ON 52.4

*All methods of groundwater pressure measurement require some flow of water into or out of the measuring system before the recorded pressure can reach equilibrium with the actual groundwater pressure.*

The selection of the measurement method should be made on the basis of the anticipated ground and groundwater conditions. Figure 17 should be used to select the most appropriate method of measuring groundwater pressure based on the anticipated ground and groundwater conditions.

*NOTE* For an excavation or a borehole, a large volume of water might flow before the water level reaches equilibrium with the groundwater pressure. On the other hand, some types of piezometer require only a very small change in the volume of water for the groundwater pressure to be read. The rate at which water flows through the soil depends on the permeability of the soil. The time required for a measuring system to indicate the true groundwater pressure is known as the response time and depends both on the quantity of water required to enter the system (including all pipes and tubes) to operate the pressure measuring device, and on the permeabilities of the ground (including any medium, e.g. sand or grout, placed between the pressure measuring device and the ground as part of the installation) and the piezometer. The selection of a suitable method for measuring the groundwater pressure is largely determined by the response time (see Terzaghi and Peck, 1948 [116]). Piezometers generally respond quicker in soils with large compressibility (see Gibson, 1963 [117]).

Figure 17 Typical response times for various piezometers



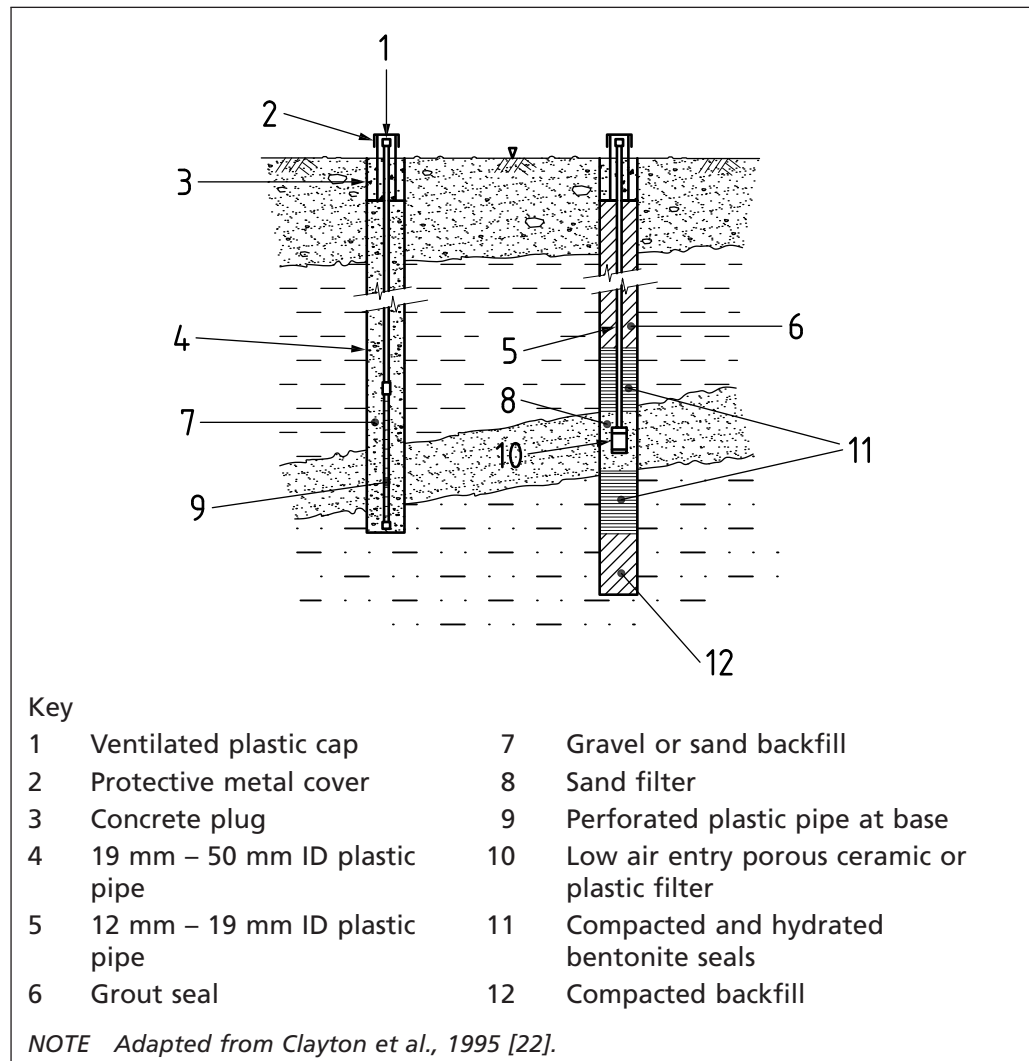
## 52.5 Standpipe piezometers

### COMMENTARY ON 52.5

A standpipe piezometer is a device consisting either of a tube or pipe with a porous element on the end, or with a perforated end section surrounded by or wrapped with a filter, which is sealed into the ground at the appropriate level. It is normally installed in a borehole. The basis for distinguishing between a standpipe piezometer and an observation well is how the response zone is sealed into the ground (see Clayton et al., 1995 [22] and Figure 18).

The tube of a standpipe piezometer should be of at least 12 mm internal diameter to allow air bubbles to rise freely and the top of the tube should be open to atmosphere to allow the water level inside the tube to come to equilibrium with the pore water pressure in the ground. Access to the top of the standpipe should be given to allow the water level to be measured. This should normally be done using an electric dip-meter, which gives an audible “beep” or light or both when it makes contact with the water or it may be done by placing a pressure sensor at the bottom of the standpipe and relating the measured pressure to the water level.

Figure 18 Examples of observation well and standpipe piezometer construction



When using a pressure sensor it should be taken into account that the sensor displaces water during placement and, therefore, the initial water level is out of balance with the pore water pressure. If the sensing part of the pressure sensor is sealed from contact with the surrounding atmosphere, the measurements should be adjusted for changes in the barometric pressure. Problems might be encountered when trying to take measurements in very cold weather due to freezing of the water inside the standpipe at elevations close to the surface. After a standpipe piezometer has been installed, its functionality should be checked by either adding or removing water to the standpipe and observing the subsequent response of the device to the out of balance head. Acceptance of the functionality should be determined on the basis of the observed response when compared to the expected performance of the device in the context of the permeability of the surrounding ground.

*NOTE 1* A frequently used standpipe piezometer is the Casagrande-type shown in Figure 18.

*NOTE 2* The main advantages of a standpipe are that it is simple and it can be used to determine the permeability of the ground in which the tip is embedded (see Section 7). The disadvantage, however, is the length of time taken to reach equilibrium or to respond to changes in pore water pressure in soils of relatively low permeability (see Figure 17) can be long.

## 52.6 Hydraulic piezometers

### COMMENTARY ON 52.6

*Hydraulic piezometers normally consist of a small piezometer tip (a water filled chamber with porous, normally ceramic walls), small-bore water filled plastic tubes and a remote pressure measuring device such as a pressure transducer and electrical readout, or more simply a Bourdon gauge. Hydraulic piezometers are frequently installed directly in trenches, but can also be installed in boreholes.*

*The most common type of hydraulic piezometer is the twin-tube piezometer (see Bishop, Kennard and Vaughan, 1964 [118]) shown in Figure 19. In this, the piezometer tip is connected to the measuring device by two tubes, so that water can be circulated to flush out any air.*

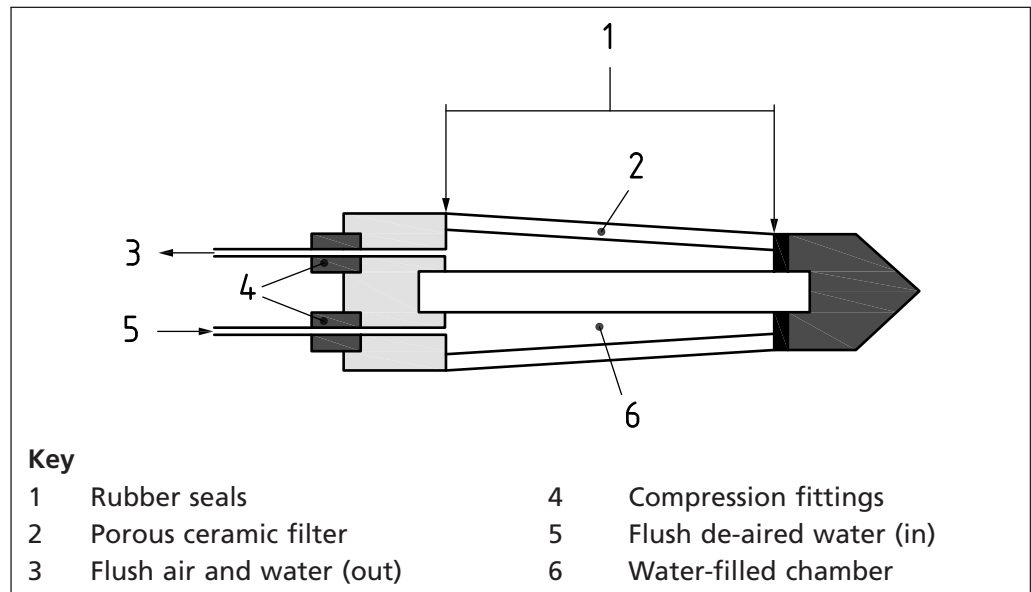
*Hydraulic piezometers usually have quick response times, although the time to respond is affected by the length of the hydraulic tubes (see Figure 17). They can be used for in-situ measurements of permeability.*

*Twin-tube hydraulic piezometers can be used for measuring a limited range of negative pore water pressures (i.e. suction). An adaptation of the traditional twin tube hydraulic piezometer is the flushable piezometer (see Ridley et al., 2003 [119]) shown in Figure 20. This piezometer incorporates a hydraulically operated shuttle valve that is used to isolate the sensor, which is located immediately behind the filter, from the flushing tubes, thereby enabling the piezometer to measure the maximum pore water tension, irrespective of the depth of installation. The hydraulic valve is screwed into the bottom of a plastic tube with a ceramic filter at the bottom of it. If air forms in the piezometer it can be removed by opening the valve and circulating de-aired water around the system. This piezometer also has the advantage that the calibration of the sensor can be checked in situ by comparing the pressure measured by the sensor with the known head of water when the valve is open and all of the air has been removed from the system. If the calibration has drifted the valve and the pressure sensor can be removed and replaced.*

*Hydraulic piezometers have also been adapted to the measurement of groundwater levels at multiple points within the same borehole (see Black et al., 1986 [120]) To do this a central access pipe is installed and the levels where pore water pressures are to be measured are isolated using packers placed either side of the measuring point, between the borehole and the access pipe. A mechanical valve located at the level of the measuring point allows fluid to be circulated and air to be purged. A measurement probe attached to a wireline is subsequently lowered to each measurement point in turn and sealed against a measurement port using a mechanical shoe.*

If the pressure in the piezometer system drops below atmospheric pressure, air can form in the system causing erroneous readings; therefore the chamber and the tubes should be kept full of de-aired water. Circulation of water through the tubes and the chamber should be done slowly so that the pressure at the measurement point is left as close as possible to the working pressure. The tubing should also be ductile and in service should be able to accommodate any strains (e.g. settlement) that might be generated in the surrounding soil. Frequent (e.g. every 5 m) coils should be included in the tubing when laying it in trenches.

Figure 19 Schematic of a Bishop-type twin-tube piezometer



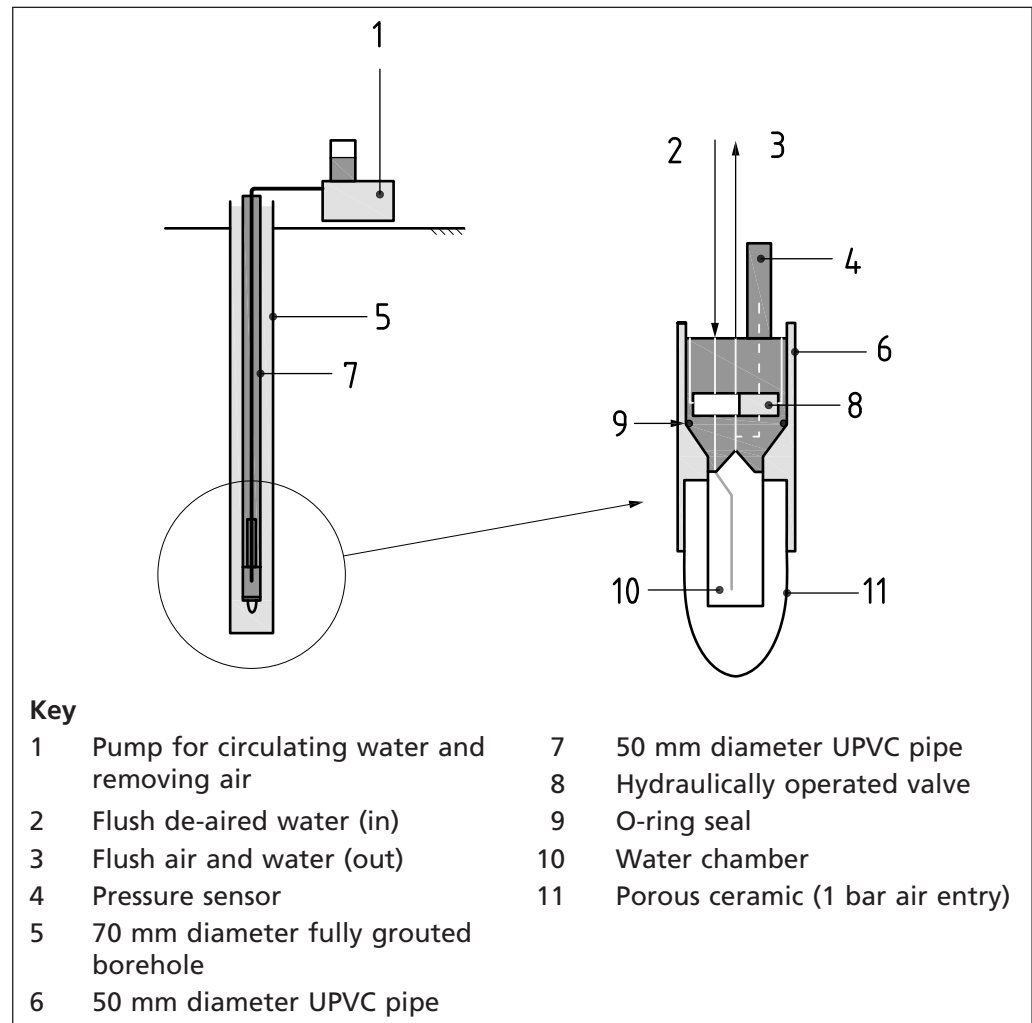
In strata with high permeability, care should be taken when using hydraulic piezometers to measure the permeability to ensure that the limiting permeability of the porous tip is higher than that of the surrounding ground.

When trying to measure negative pore water pressures (suctions), any hydraulic seals should be able to withstand the suctions without leaking. The level of the sensor relative to the filter should be taken into account when installing hydraulic piezometers in boreholes.

*NOTE* For every metre that the sensor is positioned above the filter the maximum recordable tension reduces by 10 kPa. Since the maximum pore water tension that can be measured with this type of piezometer is about 80 kPa, a few metres difference in elevation severely restricts their operational range.

In circumstances where the pore water pressure could vary from positive to negative values (e.g. vegetated clay slopes and embankments), a flushable type of piezometer should be used (see Figure 20).

Figure 20 Schematic of a Ridley-type flushable piezometer



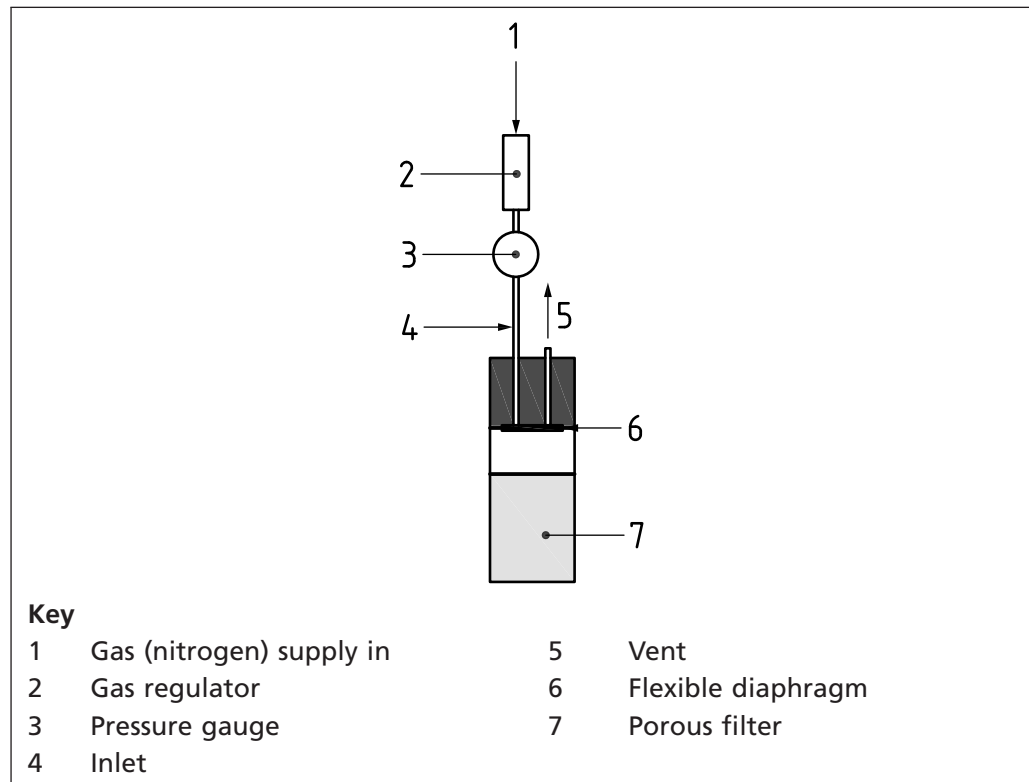
## 52.7 Pneumatic piezometers

### COMMENTARY ON 52.7

Pneumatic piezometers consist of two gas-filled tubes connecting a measuring point to a valve located close to a porous element (see Figure 21). When the gas pressure in the input line equals the water pressure in the porous element, the valve opens, the gas flows around the system and can be detected as it emanates from the return tube. The gas supply is then shut off and the pressure in the supply tube is monitored as it decays. The pore water pressure is taken to be the final steady pressure developed when the valve closes. The operation of the valve requires a small volume change in the porous element, and in stiff low permeability clays this can lead to difficulties. Pneumatic piezometers are simple to install, but they can be slow to respond because the operator has to wait for the gas pressure to equalize. They cannot be used for in-situ permeability measurements (see Penman, 1960 [121]).

Dirt entering the tubes can prevent the valve operating properly and, therefore, the operating system should be kept scrupulously clean. Care should be taken to include coils in the cables when laying them in trenches, to avoid them being stretched when strains (e.g. settlements) are encountered.

Figure 21 Schematic of a pneumatic piezometer



## 52.8 Vibrating wire piezometers

### COMMENTARY ON 52.8

*Vibrating wire piezometers consist of a flexible diaphragm separated from a porous filter by a water-filled chamber (see Figure 22). A tensioned wire is attached to the midpoint of the diaphragm on the opposite side to the water chamber, such that deflection of the diaphragm causes the wire to change in length. When the wire is caused to vibrate by "plucking" it using an electromagnet, the frequency of vibration varies with the tension in the wire and hence the pressure of the water in the chamber. The cavity containing the vibrating wire is normally hermetically sealed to prevent the ingress of moisture, which can disturb the functionality of the vibrating wire, but vented versions are available. The calibration of vibrating wire piezometers is rarely linear and, therefore, non-linear calibration coefficients are required. The calibration cannot be checked after the piezometer has been installed, which is a significant disadvantage.*

*Vibrating wire piezometers cannot be used for in-situ permeability measurements (see Penman, 1960 [121]). The very small volume of water in vibrating wire piezometers means that they respond very quickly. The measurement unit is frequency so there is no voltage in the wire and the measurements are, therefore, independent of the length of the wire. Accordingly very long cable lengths can be used.*

*When fitted with a low permeability porous filter, vibrating wire piezometers are capable of measuring small negative pore water pressures (e.g. to around  $-90$  kPa), but as these pressures reduce, the tendency for air to form in the piezometer increases and if the air is not removed the piezometer gives misleading measurements.*



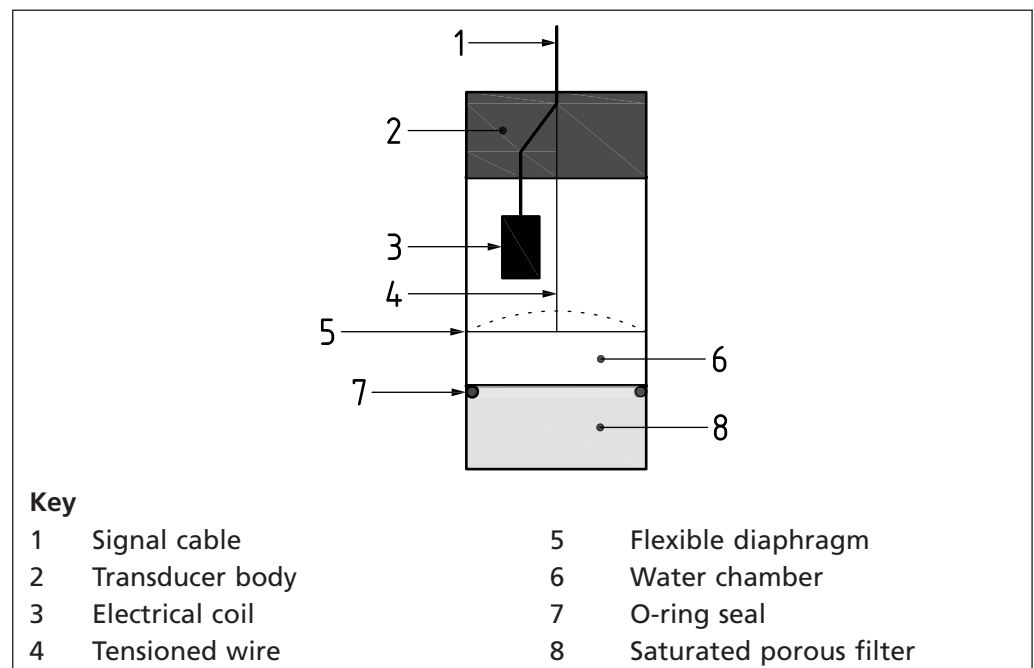
If hermetically sealed devices are used, the measured pressure should be corrected for the effect of changes in the barometric pressure at the surface. If the vibrating wire chamber is vented to atmosphere via the electrical cable, there is no requirement to record the barometric pressure but precautions should be taken to prevent moisture entering the vent tube (e.g. place a silica gel bag close to the open end of the vent tube and ensure that the system is free to "breathe").

The piezometer's calibration should be checked before it is installed by first laying it on the ground to check the zero value and then by progressively lowering it into a water-filled borehole.

Care should be taken to include coils in the cables when laying them in trenches, to avoid them being stretched when strains (e.g. settlements) are encountered.

Vibrating wire piezometers should not be used if the pore water pressures are likely to be negative and could remain so for a long time unless there is a means of removing air from the piezometer.

Figure 22 Schematic of a vibrating wire piezometer



## 52.9 Electric piezometers

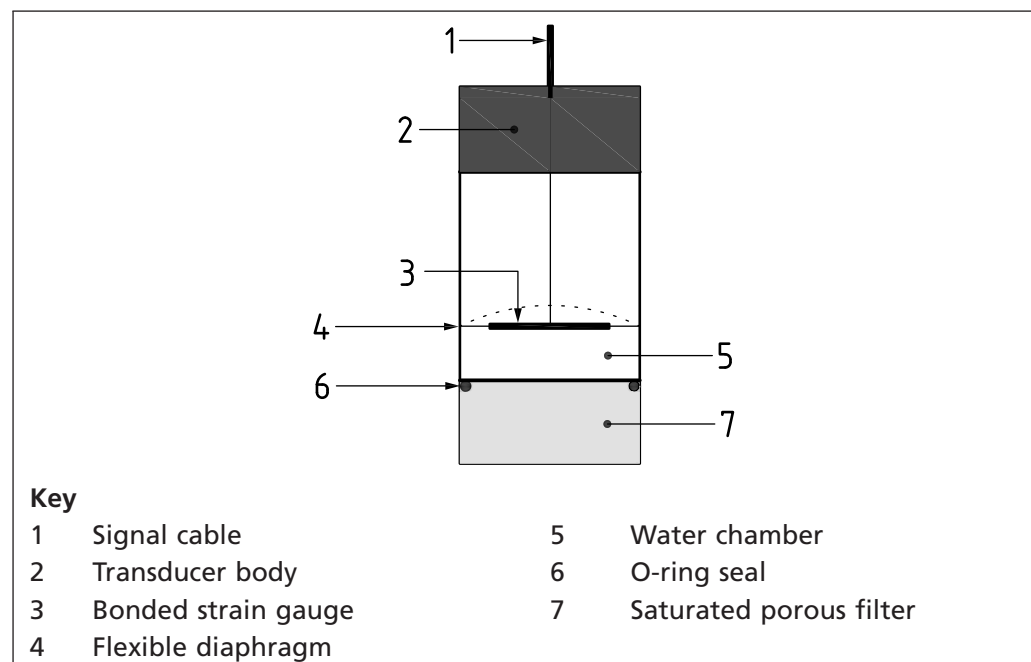
### COMMENTARY ON 52.9

*Electric piezometers consist of a flexible diaphragm separated from a porous filter by a water-filled chamber (see Figure 23). A strain gauge attached to the back of the diaphragm measures the deflection of the diaphragm in response to changes of the water pressure in the chamber. Provided the piezometer is fully saturated, very rapid response times can be achieved which makes electric piezometers particularly suitable for dynamic measurements. The measurements can be made using either a current-loop or voltage. In the case of current-loop sensors, the measurement is not affected by the length of the cable. Voltage measurements, on the other hand, are sensitive to the length of cable. The calibration cannot be checked after the piezometer has been installed, which is a significant disadvantage. Electric piezometers cannot be used for in-situ permeability measurements (see Penman, 1960 [121]). When fitted with a low permeability porous filter, electrical piezometers are capable of measuring small negative pore water pressures (e.g. to around  $-90$  kPa), but as these pressures reduce, the tendency for air to form in the piezometer increases and if the air is not removed the piezometer gives misleading measurements.*

If hermetically sealed devices are used, the measured pressure should be corrected for the effect of changes in the barometric pressure at the surface. If the sensor chamber is vented to atmosphere via the electrical cable, there is no requirement to record the barometric pressure but precautions should be taken to prevent moisture entering the vent tube (e.g. place a silica gel bag close to the open end of the vent tube and ensure that the system is free to “breathe”).

For devices reading voltage, the length of the cable should not be changed after the piezometer has been installed because it is likely to affect the calibration of the piezometer. The calibration should be checked before the piezometer is installed by first laying it on the ground to check the zero value and then by progressively lowering the piezometer into a water-filled borehole.

Figure 23 Schematic of an electric piezometer



Electric piezometers should not be used if the pore water pressures are likely to be negative and could remain so for a long time unless there is a means of removing air from the piezometer.

Care should be taken to include coils in the cables when laying them in trenches, to avoid them being stretched when strains (e.g. settlements) are encountered.

## 52.10 Installation of piezometers

Great care should be taken during installation and sealing of a piezometer or a standpipe to ensure a functioning instrument which can provide reliable pore water pressure measurements. In the case of vibrating wire and electric piezometers, the porous element should be fully saturated and filled with de-aired water before installation and the calibration should be checked as described above.

The porous element can be pushed or driven into position. If the porous element is to be pushed through cohesive soils it should be ensured that it does not become clogged or damaged. This can be achieved by using a drive-in piezometer with a removable sleeve, which covers the element during driving (see Parry, 1971 [122]), or by pre-boring a hole to the required depth and pushing the porous element a shorter distance.

*NOTE 1 The action of pushing or driving might set up high excess pore-pressures, which in soils of low permeability can take a long time to dissipate. In harder ground, the instrument is installed in a borehole and the space between the piezometer and the edge of the borehole is filled with a porous material.*

The space between the porous element and the edge of the borehole can be filled with a coarse sand, placed under water and compacted to provide a uniform filter with the porous element of the piezometer located at the centre of the filter. If sand is used the space immediately above and below the sand should be occupied by thin layers of bentonite (formed using small bentonite balls) to ensure that the flow into the filter is predominantly radial. The space above the upper bentonite plug should be filled with a cement-bentonite grout (see Table 34).

*NOTE 2 Forming a reliable sand filter can be difficult, particularly in deep boreholes and where more than one piezometer is required in a borehole at different elevations. Replacing the sand filter and bentonite seals with a cement-bentonite grout that has a suitable permeability simplifies the installation of piezometers. Whilst this approach might seem unusual because grout could be expected to inhibit the response of a piezometer to changes of the pore water pressure, it has been shown that the permeability of the grout can be less than and up to 1 000 times greater than the permeability of the surrounding soil without causing any significant error in the measured pore water pressure. See Vaughan, 1969 [123] and Contreras et al. [124] – Vaughan also showed that with care this method can be applied to open standpipes in clay ground.*

The fully grouted method of installation should be used in ground where grout losses are unlikely (e.g. clays) as it is simple and it is likely to improve the consistency of piezometer installations. It should be ensured that the piezometer stays at the required elevation and that it does not move upwards in the borehole as the grout is placed.

The composition of grout for use with piezometers depends on a variety of factors, such as the availability of materials, the required permeability, the type and make of bentonite, the condition of the borehole and the groundwater levels. The grout should be easily pumped, flexible and of the required permeability. A typical mix might be 2.5 parts water, 1 part ordinary Portland cement and 0.30 parts to 0.75 parts bentonite (depending on the ambient temperature). This produces a grout with a permeability close to  $10^{-8}$  m/s (see Wan and Standing, 2014 [125]). The cement should be added to the water first and the bentonite should then be added slowly to avoid segregation. If negative pore water pressures are anticipated, a richer mix (e.g. 1 part water to 1 part cement, with about 0.2 parts bentonite) should be used because the final permeability of the grout is low enough to restrict the passage of air into the piezometer (see *TRL Report TRL555* [126]).

Table 34 Typical cement-bentonite grout mixes for piezometers

| Applications             | Predominantly positive pressures                     |                 | Predominantly negative pressures  |                 |
|--------------------------|--|-----------------|---|-----------------|
|                          | Volume/mass  | Ratio by weight | Volume/mass   | Ratio by weight |
| Water                    | 60 L   | ~2.5            | 30 L  | 1.2             |
| Ordinary Portland cement | 25 kg  | ~1.0            | 25 kg   | 1.0             |
| Bentonite                | 18.5 kg  | ~0.74           | 5 kg  | 0.2             |
| Notes                    | The permeability of this mix is about $10^{-8}$ m/s. |                 | The permeability of this mix is about $10^{-10}$ m/s and the air entry value is greater than 100 kPa. |                 |

## 53 Inclinometers

### 53.1 General

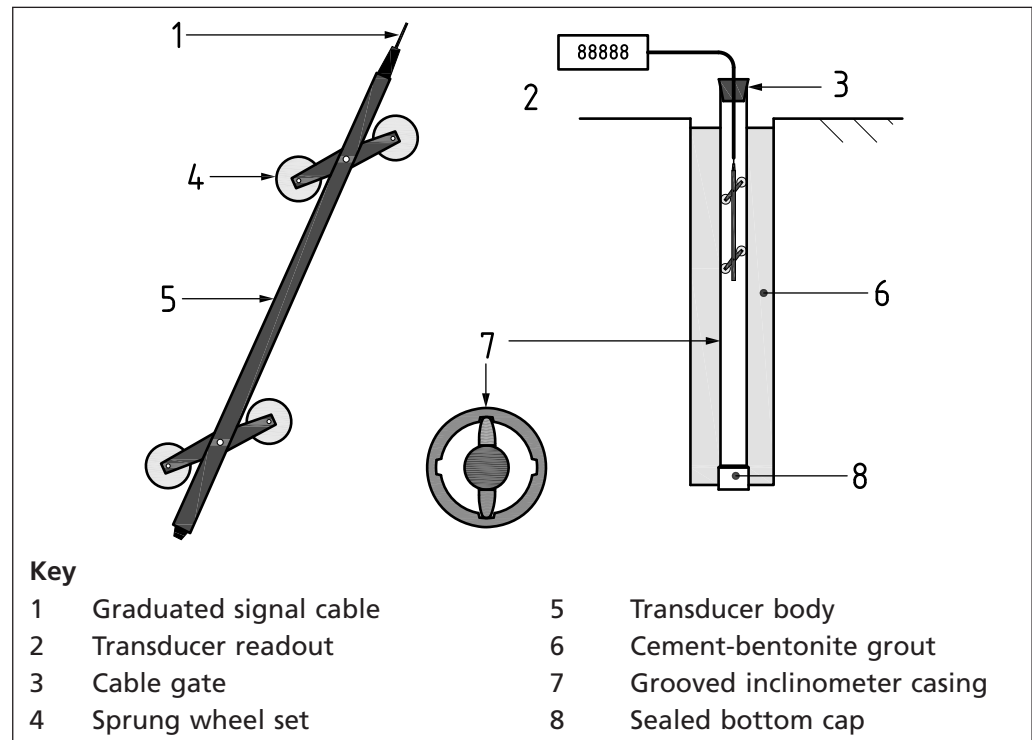
#### COMMENTARY ON 53.1

*Inclinometers are used for measuring displacements across a line in, for example, embankments, slopes, piles, diaphragm walls and tunnelling. Each inclinometer consists of a tube (known as the inclinometer access casing) with four orthogonal internal grooves, a probe (known as the inclinometer probe) and a readout device (see Figure 24). Inclinometers can be used in vertical, horizontal and inclined boreholes. Only vertical installations are described in detail in this British Standard. Information about horizontal and inclined inclinometers, together with other methods of measuring settlement and heave (e.g. hydrostatic profilers) can be found in Dunicliff, 1988 [112], ICE, 2012 [114] and BS EN ISO 18674.*

Inclinometer installations and measurements should conform to BS EN ISO 18674.

The probe and the readout device should be connected together using a graduated cable. The graduation markers may also act as hangers for supporting the inclinometer probe. The inclinometer probe should normally have two sprung wheel sets, one at either end, which are used to locate the probe along the grooved tube using the cable. At regular and known locations inside the inclinometer access casing, the inclination of the casing should be measured using the inclinometer probe. The measured inclinations should be used to calculate the shape of the inclinometer casing; displacements of the casing should be calculated by subtracting the initial shape of the casing from the current shape of the casing.

Figure 24 Probe inclinometer system



### 53.2 Inclinometer access casing and installation procedure

#### COMMENTARY ON 53.2

*Inclinometer access casings are most often formed of ABS (acrylonitrile butadiene styrene), but aluminium casings are also available. Individual sections of casing are usually 3 m long and flush jointed with an O-ring seal to prevent ingress of grout or water. Couplers are available and can be used where sections of casing have no O-ring joint or where a length of casing has been cut. The couplers are either glued or riveted to the sections.*

The joints should be sealed to prevent ingress of water or grout; if rivets are used, the coupler should be covered with a waxed tape. A sealed bottom cap should be used and the top of the casing should be covered during installation. Spiralling of the internal grooves should be quantified over the whole length of the installed casing before any readings are taken. If spiralling of the grooves is greater than  $\pm 5^\circ$  over the length of the casing this should be taken into account when calculating the resultant inclinations.

Inclinometer casings should be installed inside boreholes or, in the case of piles and diaphragm walls, installed inside temporary void formers placed inside the structure until concreting is complete. The annulus between the inclinometer access casing and the ground or temporary void former should be filled with a cement-bentonite grout. Typical grout mixtures for stiff and soft ground are shown in Table 35 (see Mikkelsen, 2002 [127]). The cement should be added to the water first because the strength and stiffness of the grout are determined by the initial water/cement ratio. Bentonite is only added to restrict "bleed". Sufficient bentonite should be added to provide a creamy mix, which is pumpable. The amount of bentonite required to provide this depends on the ambient temperature and the acidity of the water. Care should be taken to prevent the grout from entering inside the inclinometer access casing during installation.

Where significant grout losses occur (e.g. in heavily fractured or voided ground and where the surrounding ground has a high permeability) it might not be feasible to satisfactorily fill the annulus between the access casing and the ground with grout. In these circumstances the annulus may be filled with a granular material (e.g. pea gravel). Care should be taken to ensure satisfactory backfilling and restraint are provided. Consideration should be given to drilling larger diameter boreholes so that there is sufficient annular space to prevent bridging of the gravel.

Table 35 Typical cement-bentonite grout mixes for inclinometers and extensometers

| Applications                    | Medium to high strength soils   |                 | Soft soils and extensometers                                 |                 |
|---------------------------------|---|-----------------|--|-----------------|
|                                 | Volume/mass   | Ratio by weight | Volume/mass  | Ratio by weight |
| <b>Water</b>                    | 60 L  | ~2.5            | 50 L   | 6.6             |
| <b>Ordinary Portland cement</b> | 25 kg   | ~1.0            | 8 kg   | 1.0             |
| <b>Bentonite</b>                | 7 kg  | ~0.3            | 3 kg   | 0.4             |
| <b>Notes</b>                    | The 28 day compressive strength of this mix is about 350 kPa and the Young's modulus is about 69 MPa. |                 | The 28 day compressive strength of this mix is about 28 kPa. |                 |

*NOTE Adapted from Mikkelsen, 2002 [127].*

The weight of the inclinometer access casing is much less than the equivalent upward force exerted on the bottom of the casing by the grout, which means that the casing quickly becomes buoyant and starts to float in the grout. This should be countered by filling the inclinometer access casing with water as it is installed or placing a heavy rod (e.g. an SPT rod) inside the casing. If, however, the annulus between the casing and the ground is filled to the top (i.e. the surface) with grout, the weight of a water-filled tube is unlikely to be sufficient to counter the uplift force and in such circumstances either an anchorage system should be used at the bottom of the casing or the annulus should be filled in two or more stages. Once grout has set around the bottom of the inclinometer access casing and it is effectively isolated from the effect of the pressure generated by the grout that is added to the annulus, it ought to be possible to fill the annulus to the top without the casing rising due to buoyancy. Weight should never be applied to the top of the inclinometer access casing to counter the effect of the buoyancy, as this causes the casing to buckle and leads to a reduction in the quality of the resulting measurements.

Each inclinometer access casing should be installed with one pair of grooves orientated in the direction of the expected movement (e.g. up/down a slope and towards the excavation for a diaphragm wall). Orientation of the casing should be done before any grout is placed inside the borehole or void former. The casing should never be rotated inside the borehole or void former after the grout has been added to the annulus as this might cause the casing to become spiralled or misaligned. If none of the grooves are aligned with the direction of likely movement, the casing should be left in the same orientation and the measurements should be resolved to determine the displacements.

For near vertical installations, the inclination of the borehole or void former should be no more than  $\pm 5^\circ$  to the vertical in all directions. The bottom of the inclinometer access casing should be located below where any expected lateral displacement occurs and this condition should be satisfied over a length of casing equivalent to at least five measurements (e.g. 2.5 m in the case of a 0.5 m inclinometer probe). If this is not possible, the absolute position of the top of the inclinometer access casing should be determined by surveying.

The grout should be allowed to set before any measurements are taken inside the inclinometer access casing. Typically this can take a few days but it is dependent on the mix used and the temperature.

Where inclinometer access casings are installed inside horizontal boreholes the bottom of the casing is in direct contact with the ground. The space above the casing should be filled with a cement-bentonite grout. Temporary, expandable packers should be used to retain the grout in the borehole until it has set. When the access casing is placed in a shallow trench (e.g. for measuring settlements beneath an embankment) a geotextile and a shallow layer of fine sand should be used between the access casing and the ground.

### 53.3 Inclinometer measurement procedure

Measurements should be taken as follows.

- a) Place the inclinometer probe carefully into the inclinometer access casing, orientated so that positive inclinations are measured in the direction of the expected movement.
- b) Lower the inclinometer probe slowly to the bottom of the inclinometer casing, taking care that it does not hit the bottom of the casing in a manner that might damage the probe or disturb its calibration.
- c) Suspend the probe near to the bottom of the casing, without it touching the bottom, using the graduated cable supported on a specially designed "cable gate" and leave it there for at least 10 min to reach thermal equilibrium with the surroundings.
- d) Take the first reading and raise the probe by a distance equal to the distance between the sprung wheels (normally 0.5 m).
- e) When the probe stabilizes at the new location, take another reading and raise it again. This process continues until the probe reaches the top of the inclinometer access casing, when it is carefully removed from the casing, avoiding any knocks (including the sudden opening of the sprung wheels).
- f) Turn the probe through  $180^\circ$  and lower it back to the bottom of the inclinometer access casing. The process is then repeated until the probe reaches the top of the casing again. This constitutes a full set of readings and the time and temperature should be recorded.

As the probe is raised, the operator should check the sum of the measurement in the  $0^\circ$  direction and the measurement in the  $180^\circ$  direction for each pair of readings at the same elevation.

*NOTE This is known as the "check sum" and can be used to reveal inconsistencies between the measurements caused for example by skipping or duplicating a reading, or by not waiting long enough for a reading to stabilize properly.*

Horizontal casings should have access to both ends so that one person can pull the probe through the hole and maintain the horizontal positioning of the probe by pulling against the cable gate when the probe reaches the required position. Horizontal inclinometer probes have one fixed wheel and one sprung wheel. The fixed wheel is placed in the lower groove and the sprung wheel is placed in the upper groove. For horizontal access casings, the absolute position of at least one end of the casing should be measured using survey techniques at the same time as the inclinometer measurements.

#### 53.4 Calculations

The profile of the inclinometer casing should be calculated as follows.

- a) Subtract the reading at a particular depth from the reading at the same depth but in the reverse ( $180^\circ$ ) orientation and halve the result. This is performed for each depth.
- b) Calculate the results from a), starting at the fixed end of the inclinometer access casing. The resultant profile verses depth is known as the cumulative deviation.
- c) Cumulative displacements are calculated by subtracting the current cumulative deviation from the initial cumulative deviation.

#### 53.5 Errors and their adjustment

Immediately following the completion of a set of readings, the current cumulative deviation of the inclinometer access casing should be calculated and compared to the most recent cumulative deviation to confirm that the readings are representative. However, this does not confirm that the readings are free from error and further checks for bias shift, cross-axis error and other errors should be carried out to determine this (see Mikkelsen, 2003 [128]).

*NOTE 1 The most common form of error is bias shift, which occurs when an inclinometer probe is knocked or the sensor's zero is drifting. Ideally, an inclinometer probe reads zero when it hangs in a true vertical position. This is, however, difficult to achieve, so the probe is rotated through  $180^\circ$  so that it reads small equal and opposite values in each direction when hanging vertically. If the probe is knocked during a set of readings, which is likely to occur as it is removed from the casing, turned through  $180^\circ$  and lowered back to the bottom of the casing, it might not give equal and opposite readings when hanging truly vertical. If that is the case, equal and opposite values are not likely to be given when inclined. The difference between the readings in reverse orientation when truly vertical is known as the "bias shift". This type of error causes false displacements to appear over the whole length of an inclinometer access casing, the magnitude of which is normally the same for each reading. The error can be corrected if a length of the casing is known to have not moved since the monitoring programme commenced because the displacement appears as a uniform lean in the casing relative to the depth axis and starting at the "zero" end. The false displacement associated with each reading is, therefore, calculated and subtracted from the actual measurements to give a profile that is near vertical over the depth where the casing is known to have not moved. The same unit correction is then applied to all elevations of the casing.*



*NOTE 2* “Cross-axis” or “rotational” error occurs when an inclinometer access casing is inclined at a large angle in the orthogonal direction to the direction in which the measurements are taken. The error shows itself if the sensor that is reading the inclination of the probe is not properly aligned with the direction of movement and starts, therefore, to sense movement due to its inclination in the cross-axis direction. “Rotational” error is much harder to distinguish than “bias” error as they frequently look similar. Generally, however, it is identified by comparing the displacement profile of the inclinometer access casing with the absolute profile of the inclinometer casing in the direction that is perpendicular to the direction of the measurements. If the profiles are similar in shape it is likely that some “rotational” error is present. The error is removed by distributing it in proportion to the deviation from vertical.

If systematic errors of the measurement, such as those described in Note 1 and Note 2, can be identified and not adjusting the data would result in the measurements falling outside the required accuracy, then data processing should include adjustment of the measurements. Computer software for adjusting and presenting inclinometer results is available from most manufacturers of inclinometer probes and through independent companies.

Other errors can be introduced into inclinometer surveys by poor depth positioning, sensor drift and spiralling in the grooves of the casing, but good installation procedures and regular maintenance of the inclinometer equipment should be employed to avoid these.

### 53.6 Presentation of inclinometer measurements

When all of the systematic errors have been removed from an inclinometer survey the remaining error is random and should be no more than  $\pm 0.16 \times \sqrt{\text{number of readings}}$  (see Mikkelsen, 2003 [128]). This should be shown as a function of depth on the graph of cumulative displacement versus depth, as a means of demonstrating that systematic errors have been removed and that no displacement is occurring over the length of the casing that is known to be stable. When inclinometers are used to detect displacements in slopes and a well-defined plane of distinct displacement (i.e. a shear plane) is likely to develop, the change in inclination can be plotted relative to the initial inclination (known as the incremental deviation) at each depth, rather than the cumulative displacement. This has the advantage of not accumulating systematic error and, therefore, requiring less analysis. If, however, a unique shear plane is not likely to develop (e.g. in piles and diaphragm walls), an incremental deviation profile shows nothing useful and a cumulative displacement profile should be used.

### 53.7 In-place inclinometers

#### COMMENTARY ON 53.7

*Where automatic or remote data collection is required, a continuous string of inclinometer sensors can be installed inside the access casing and connected to a datalogger at the end of the access casing.*

Each sensor should be connected to the adjacent sensor using stiff gauge tubes and flexible joints. The lengths of the gauge tubes should be selected based on the initial deviation profile of the access casing and to ensure that the gauge tubes do not interfere with the inside surface of the access casing as it is deformed. Gauge lengths greater than 2 m should be avoided.

*NOTE In-place inclinometer measurements do not need to be adjusted for “face errors” because the orientations of the sensors (i.e. 0° or 180°) are fixed throughout the life of the instrument. The absolute shape of the inclinometer casing recorded by in-place inclinometers is not necessarily as accurate as the shape determined using an inclinometer probe. Long gauge tubes can also introduce significant errors into the calculation of shape and, therefore, displacements, particularly where bends such as a shear distortion are expected.*

## 54 Extensometers

### 54.1 General

#### COMMENTARY ON 54.1

*Extensometers are used for measuring changes of distance between two or more measuring points located along a measuring line in, for example, embankments, slopes, piles, diaphragm walls and tunnelling.*

In ground, the measuring points should typically be installed in boreholes and the measuring line should coincide with the axis of the borehole. At each measuring point the movements of the medium (e.g. soil, rock and concrete structures) being investigated should be transferred to the measuring point by anchors. The anchors, which are fixed to the measuring points, should make good contact with the medium being investigated. Two types of extensometer are commonly used, magnetic probe extensometers and rod extensometers.

Extensometer installations and measurements should conform to BS EN ISO 18674.

### 54.2 Probe extensometers

#### COMMENTARY ON 54.2

*Magnetic probe extensometers consist of a hollow stiff non-magnetic central flush access pipe (typically of 33 mm diameter), through which a magnetic reed switch is passed. Each measuring point (commonly known as a “spider magnet” because of its appearance) consists of a plastic doughnut containing magnets and has legs (typically three or six) made from sprung steel (see Figure 25). The spider magnets are threaded over the access pipe and positioned where the movements are to be measured. When a magnetic reed switch is lowered into the access pipe the magnetic field generated by a spider magnet causes a reed inside the switch to close, forming an electric circuit and a buzzer is activated.*

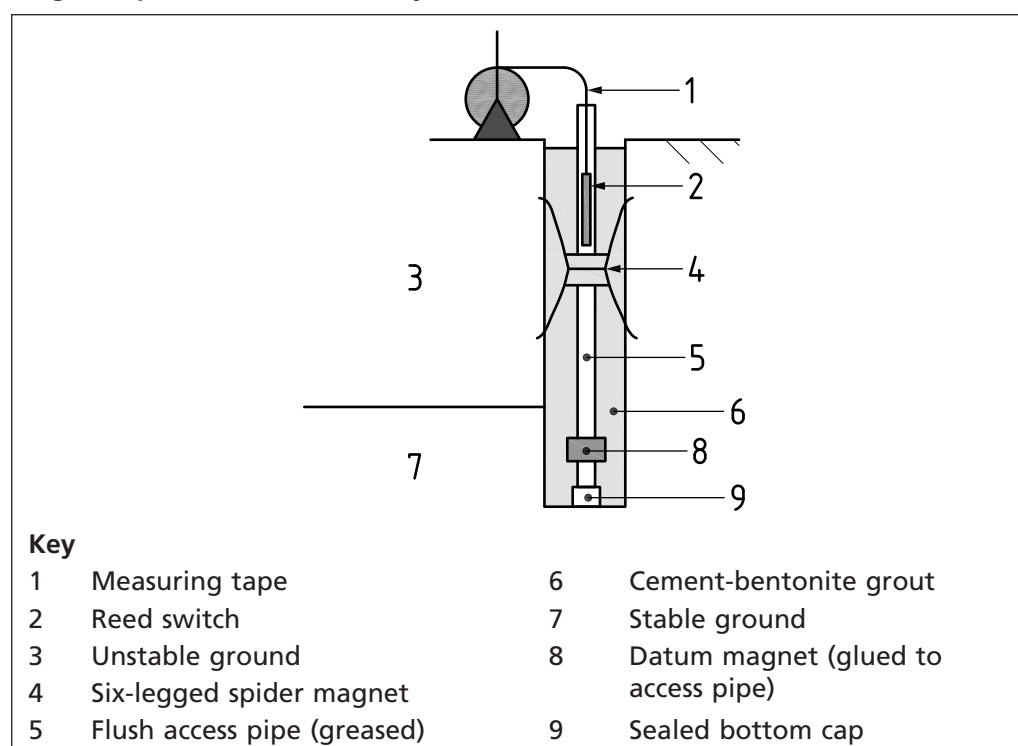
The open diameter of a spider magnet’s legs should be wide enough to make contact with the surrounding ground when opened and the borehole should be filled with a soft, deformable cement-bentonite grout. The position of the spider should be measured, relative to the top of the access pipe using a measuring tape connected to the reed switch. The absolute location of the spider magnets should be evaluated by either positioning a datum magnet, glued to the access casing at a depth below where the movements are expected to cease (i.e. in stable ground) or more reliably by precise levelling the top of the access casing at the same time as the measurements are made.

*NOTE The main problem with magnetic probe extensometers is that it can be very difficult to position the spider magnets accurately. The sprung legs are frequently held back during insertion using a rubber band and when a spider reaches the correct depth the rubber band is cut or removed and the legs unfold. Their sprung nature causes them to dig into the surrounding ground and this can be unreliable, particularly in stiff ground. Moreover, it is not unusual for the rubber band to release before the spider reaches the required depth or for users to, therefore, find it difficult to position the spiders accurately.*

To avoid this problem, spiders with three rather than six legs can be used and inserted over the access casing with the legs pointing upwards. The spider is pushed to the required location using an insertion pipe/tool that also fits over the access pipe. If the insertion tool and the spider are connected using a bayonet fixture the spider can be pulled when the required location is reached causing the legs to dig into the ground and the bayonet can be released to remove the insertion tool. In stiff unsupported ground the legs of the spider scrape along the edges of the borehole during insertion. In soft ground it might be necessary to use a drilling support casing and the spider can be pushed to the bottom of the drilling casing when the latter is close to the required location and then pushed beyond the bottom of the casing before releasing the bayonet connector.

Some larger spiders are made for insertion over flush inclinometer casings, but if they are used, care should be observed to use an appropriate grout because to function correctly the spiders need a soft, deformable grout, whereas the inclinometer might need a stiffer grout (depending on the ground conditions).

Figure 25 Magnetic probe extensometer system



### 54.3 Rod extensometers

#### COMMENTARY ON 54.3

Rod extensometers consist of anchors, connecting rods and a measuring head. Each anchor is positioned at a measuring point and joined to a connecting rod, running to the measuring head, which is normally located at the ground surface (see Figure 26). At the measuring head is a means of measuring the position and change in position of the connecting rods and hence the anchors. This can be electric displacement transducers connected to the measuring head or else the position of the rods can be measured using a portable dial gauge. The latter can only be used for discrete measurements whereas displacement transducers might be connected to a data logger for automatic and remote monitoring solutions.

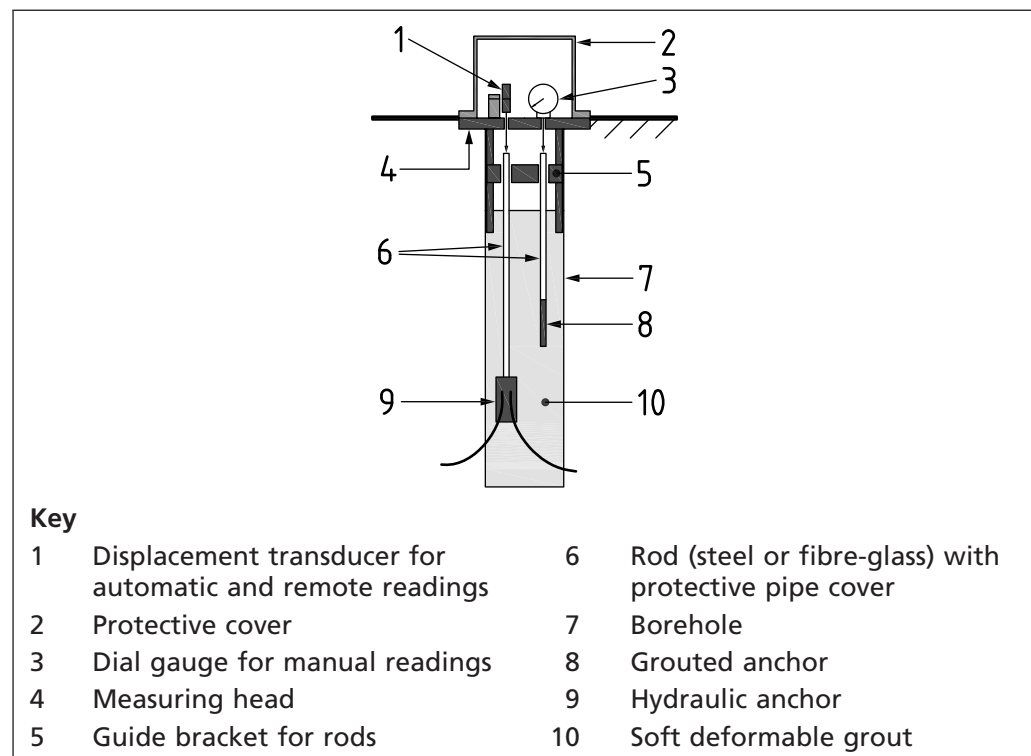
The anchors might be a grouted type, whereby there is no direct contact between the anchor and the ground and conformance is maintained through the use of a suitable grout. Alternatively the anchors might have hydraulically activated prongs that can be extended into the ground.

At least one of the anchors should be located where no displacement is expected because it can then be used as a reference for the displacements of the remaining anchors. If it is not possible to locate an anchor in stable ground, the elevation of the reference head should be independently measured using a precise level each time a measurement is made. If grouted anchors are used, the grout should be deformable because if it is too stiff the whole extensometer might move as a solid element, the movements of the anchors might be restricted and the movements at the measuring points might be underestimated.

*NOTE 1 Remote monitoring is not practical if the reference head has to be precisely levelled.*

*NOTE 2 Connecting rods are typically made from stainless steel or fibreglass and are surrounded by a plastic sleeve to isolate them from the grout that is used to fill the borehole after the anchors and connecting rods have been installed. Stainless steel rods come in discrete, relatively short sections (typically 2 m to 3 m) with screw threads on each end and are joined together during installation, the final, uppermost length being adjustable to suite the required location of the respective anchor. Fibreglass rods come in fixed continuous lengths, which are coiled for transporting and while they can be installed in one step, it is important that the anchors are positioned accurately because fibreglass rods are impossible to lengthen and difficult to shorten after they have been installed. The choice of material for the rods (stainless steel or fibreglass) is influenced by the skill of the installer to position the anchors accurately and the thermal stability of the installation.*

Figure 26 Rod extensometer system



## Section 9: Laboratory tests on samples

### 55 General

Geotechnical laboratory testing should be carried out in accordance with BS EN 1997-1, BS EN 1997-2, NA to BS EN 1997-2 and, where not covered by these standards, the various other standards and methods recommended in Table 36 to Table 42. Other test methods might be required for more complex geotechnical structures (geotechnical category 3).

The programme of investigation should be designed:

- a) to classify the samples; and
- b) to obtain parameters relevant to the technical objectives of the investigation.

*NOTE* The test methods, analysis and interpretation of laboratory test results are not covered by this British Standard.

### 56 Roles and responsibilities

The laboratory should have an organizational structure with clearly defined responsibilities. The structure should be communicated to all staff including temporary workers. All staff should have experience and knowledge commensurate with their role.

The laboratory supervisor should manage the laboratory testing activities and have knowledge and experience of the laboratory systems of work including quality assurance, health and safety systems and the requirements for the tests. The laboratory supervisor should:

- organize and co-ordinate the work of staff;
- organize training, instruction and supervision;
- select the test methods to be available;
- ensure safe working practices;
- arrange health surveillance for employees, where required; and
- check the quality of sample delivered to the laboratory is suitable for the tests that have been scheduled (where the sample is not suitable, this should be reported to the geotechnical advisor).

Laboratory technicians should have suitable training for and experience of the particular tests they undertake.

### 57 Health and safety in laboratories

#### 57.1 General

##### *COMMENTARY ON 57.1*

*For general advice on health and safety in the laboratory, see the AGS General laboratory safety document [129] and also Annex A. Attention is drawn to the Health and Safety at Work Act 1974 [130].*

The laboratory should have a safe system of working in place, which includes:

- risk assessments of each task and procedure that might cause harm to the laboratory staff, other persons or the environment (see HSE guidance documents <sup>14)</sup>);
- a contingency plan to deal with foreseeable emergencies;
- documentation of the safe systems of work; and
- an auditing and monitoring system to ensure safe working.

## 57.2 Screening of samples containing hazardous substances

The geotechnical laboratory should be informed at an early stage of the ground investigation if samples are likely to contain hazardous substances (see Section 3). The laboratory should undertake a risk assessment and decide whether testing on the samples is safe and make any necessary changes to existing health and safety and test procedures.

*NOTE 1 Additional health and safety precautions might be required relating to handling, transport and storage as well as the test procedures; any additional precautions might increase the costs.*

Any samples that are known or suspected to contain asbestos or other particularly harmful substances should be labelled with the type(s) of harmful substance in the field (see 17.8, 17.9 and 19.2.5). Samples allocated for testing in a geotechnical laboratory should be screened for the presence of harmful substances by an appropriate laboratory prior to deciding if geotechnical testing should proceed. These test results should be supplied to the geotechnical advisor and laboratory manager. The laboratory manager should decide whether a sample is safe to carry out the required tests. The geotechnical advisor should then be informed as other samples might be substituted.

*NOTE 2 The identification of a hazardous substance might require the use of different methods of sampling, sample container and storage conditions than those for geotechnical purposes (see BS 10175 for further recommendations).*

The receipt of samples known to, or likely to, contain hazardous substances should be by agreement with the geotechnical laboratory. The samples labelled as containing or likely to contain hazardous substances should be stored in a separate part of the sample store that should be identified for this use (see 58.2).

*NOTE 3 It is preferable that a geotechnical laboratory receives only those samples that are have been identified as suitable for testing.*

## 57.3 Data recording, management and transfer

The laboratory should have a data management system that covers all aspects of sample, subsample, specimen and test data (see BS 8574).

*NOTE Results are generally stored digitally and might be transferred to others using an industry standard digital data transfer format.*

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<sup>14)</sup> Available from <<http://www.hse.gov.uk/risk/risk-assessment.htm>> [last viewed 24 June 2015].

## 58 Sample storage and inspection facilities

### 58.1 General

A geotechnical laboratory should have appropriate facilities for handling, storing and inspecting samples. Samples should be preserved, handled and stored in accordance with BS EN ISO 22475-1.

### 58.2 Storage of samples

#### 58.2.1 General

The sample storage area should be of sufficient size to cater for the number of stored samples without overcrowding and to enable the samples to be readily located when required for examination or testing. Samples labelled as containing or likely to contain hazardous substances should be stored in a separate designated area. Samples should be stored so that they are protected from damage, deterioration, loss of water, and to maintain quality as required by the test methods used on that sample. Class 1 and 2 samples should be stored at an appropriate temperature.

A record of storage temperatures for Class 1 and 2 samples should be maintained.

*NOTE* Samples for chemical and geoenvironmental testing have different storage temperature requirements (see BS ISO 18512).

#### 58.2.2 Inspection facilities

A specific area should be established in the laboratory for the inspection and description of samples. This should have sufficient space for the temporary storage of the samples and an adequate area of bench space with good lighting for inspection, preferably daylight or using "daylight" artificial lighting (see Norbury, 2010 [42]). In general, the following equipment should be provided as required:

- a) an extruder for removing samples from the sample tubes or liners and a means of cutting plastic liners when extrusion is not desirable;
- b) camera, scale and other equipment (see Annex H);
- c) an adequate number of trays of suitable size to enable disturbed samples of coarse soils to be tipped out for inspection, and some means of returning them safely and quickly to their containers afterwards;
- d) spatulas, knives, hand lens, geological hammer, penknife, metre scale, protractor for logging cores, hand vane, a simple binocular microscope with appropriate magnification such as  $\times 30$ ;
- e) 10% (dilute) hydrochloric acid to assist identification of the presence of carbonate;
- f) an appropriate water supply to enable the fines to be washed out of samples of soils and facilitate description of the coarser particles; to clean rock cores and block samples; and to wet-up fine grained or any dry soils;
- g) a balance suitable for checking the mass of samples is sufficient for testing;
- h) means of resealing samples required for further use;
- i) washing facilities for personnel inspecting the samples; and
- j) gloves, overalls and other PPE as needed.

### 58.3 Sample registration and handling

#### 58.3.1 Registration

All samples entering the laboratory should be registered and receipts issued.

#### 58.3.2 Handling and labelling

All samples entering the laboratory should be clearly and unambiguously labelled and have a unique number, which might be a combination of the ground investigation identification, borehole number, sample number and/or depth or other system. The list of samples, in the form required by the laboratory (e.g. digital and paper form), should be supplied together with relevant data from site as required. Note should be taken of any warnings on the labels of likely hazardous substances and handling of such samples might require extra precautions as identified in the risk assessment. Samples should be treated with care to prevent damage particularly during transfer into the laboratory.

## 59 Selection of testing programme

The programme of laboratory testing for the project and the specification of each test should be determined by the geotechnical advisor in accordance with BS EN 1997-2 and NA to BS EN 1997-2 and other references as required for category 3 projects. Details of the tests required to determine the parameters needed for design should be specified. Each test, or series of tests, should address one or more of the purposes listed in Section 2. The principal factors that should be taken into account include:

- a) the nature of the ground and the type of soil or rock being tested;
- b) the quality of the sample;
- c) the method of analysis proposed in accordance with BS EN 1997-1 (and other methods not covered in BS EN 1997-1, such as slope stability analysis of landslides); and
- d) the requirements of the structure and the temporary works.

*NOTE Further detail on common soils tests is given in Table 36 and Table 37; on shrinkage and swell tests in Table 38; specialist soil testing that might be used for category 2 or 3 projects in Table 39; on rock testing in Table 40; tests that assess the suitability as an aggregate in Table 41 and geophysical laboratory testing in Table 42. Some tests describe and classify soils and rocks; some determine parameters used in empirical analyses and the design is based on a body of past experience, while other tests determine parameters used in more rigorous theoretical analyses. Many of the tests, together with references for soils, are given in BS 1377 and BS EN ISO 17892-1 and BS EN ISO 17892-2 (as well as BS EN ISO 17892, parts 3 to 12 as they are published) and, for rocks, in International Society for Rock Mechanics (ISRM) and American Society for Testing and Materials (ASTM) methods. Further information on soil testing can also be found in Manual of soil laboratory testing, Volumes 1 to 3 [131] [132] [133].*



## 60 Visual examination and description of laboratory samples

### 60.1 Description of samples

All test samples and specimens should be described prior to testing in accordance with Section 6 by an appropriately trained and experienced person. This should be separate from the description cores or samples forming part of a borehole or pit description (log). These descriptions should be included on the laboratory work sheet.

Some post-test samples, such as unconfined compressive and triaxial strength tests, should be described, drawn or photographed as required by the method. Visible surfaces of failure should be noted and their angle to the direction of externally applied direct loads recorded. Samples may be broken open to assess their uniformity and to identify any obvious reason for their behaviour. This should be done with care as the post-test sample might be required for water content determination. Other samples pre- or post-test should be photographed or sketched if required by the geotechnical advisor.

Appropriate comments should be made on the variability and disturbance of the samples.

*NOTE* More detailed specialist examination of samples, as required by the geotechnical advisor, might be needed, including information of the palaeontology, petrography by optical or electron microscopy to examine the fabric and texture, and mineralogical analyses.

### 60.2 Photographic records

#### COMMENTARY ON 60.2

*Photographs can be used to provide a record of cores, split tube samples, typical features or a record of atypical features.*

Photographic records should be kept as required. See Annex H for guidance on lighting and format.

*NOTE 1* Photographs of disturbed samples can be used to show details of the particle shape and grading. The photographic record of laboratory samples might be used with those from the field showing natural or excavated faces in quarries or test pits, spoil heaps and photographs of features observed during the field reconnaissance.

*NOTE 2* Photographs might be taken of samples in the "as received" state before testing and again after testing to show the mode of failure, or after splitting to show features of the fabric. Certain features might be seen more clearly after the sample has been allowed to dry or partially dry.

*NOTE 3* Photomicrographs from optical or electron microscopes might be useful on occasions for instance to aid an understanding the relationship between material structure and behaviour.

## 61 Laboratory tests

### 61.1 Sample suitability

The samples selected for testing should be appropriate for the test or tests; this includes material type, sufficient size to carry out the test or tests and suitable quality as required for the test(s) (see BS EN 1997-2 and the test method or methods). Where the sample is not appropriate for a test due to the lithology being unsuitable or to sample disturbance or insufficient material for the test(s), the geotechnical advisor should be informed and they should make the decision as to whether the test should proceed or other samples might be used. If the test is carried out on a non-conformable sample it should be reported with the reasons in the results.

*NOTE* The re-use of material for more than one test is permissible for some tests and might be included as a part of the test programme by the geotechnical advisor.

The laboratory should provide guidance to the geotechnical advisor on the largest sample that can be handled and tested at the facility.

Undisturbed samples for testing the effects of the discontinuities on strength and deformation characteristics should be sufficiently large to include a representative pattern of these discontinuities relevant to the test required. This might require use of large “undisturbed” samples.

### 61.2 Conditions of test

The conditions of the test should be those appropriate to determine the parameters required in Clause 55 and Clause 59 and the test methods and test conditions as specified by the geotechnical adviser.

### 61.3 Relevance of test results

All laboratory test results should be examined critically by a suitably qualified and experienced person, usually the laboratory supervisor. They should be examined to check the following:

- a) that the results are reasonable, correctly reported and refer to the correct sample;
- b) that the results from similar samples are consistent (i.e. results from samples with similar descriptions are comparable);
- c) that results from a particular sample are consistent with other data relating to the sample;
- d) that the results of the laboratory tests are consistent with the results of relevant borehole log descriptions and in-situ tests if available; and
- e) that the test results are consistent with previous knowledge and accepted data for similar materials.

Whenever test results appear to be anomalous, the reason should be established by re-examination of the specimen, original results or confirmed by further testing, which might include other types of investigation such as petrological or mineralogical testing. If the reasons for an unusual result cannot be established, the geotechnical advisor should be notified and the anomaly should be clearly stated in the report on the laboratory tests.

## 61.4 Reporting test results

Laboratory test results should be reported clearly, as required by the test standard or the specified test method and interpretation; this includes how the test was conducted and how the raw data obtained from the test were analysed and interpreted. The original laboratory worksheets, analogue or digital, should be kept for future reference as required by the project specifications. Data from tests should be provided in a form as required by test method and the data management plan in accordance with BS 8574.

The origin of the sample, its size and class and all procedures carried out prior to testing should be reported. In some cases, the test results should be reported factually; in other cases the test results may be interpreted and values for design parameters given.

The appearance of samples tested for strength, deformation or permeability should always be sketched and/or photographed after they have been tested. Visible surfaces of failure should be noted and their angle to the direction of externally applied direct loads recorded. Samples should be broken open to assess their uniformity and to identify any obvious reason for their behaviour.

Table 36 Categories of test specified in BS 1377 with the BS EN ISO 17892 equivalent tests

| BS 1377              | BS EN ISO 17892 <sup>A)</sup><br>equivalent or near<br>equivalent | Tests  |
|----------------------|---|--|
| Part 1 <sup>B)</sup> | –   | General requirements and sample preparation  |
| Part 2               | Part 1, Part 2,<br>Part 3, Part 4,<br>Part 12                     | Classification tests   |
| Part 3               | –   | Chemical and electro-chemical tests  |
| Part 4               | –   | Compaction related tests   |
| Part 5               | Part 5 <sup>C)</sup>  | Compressibility, permeability and durability tests                                     |
| Part 6               | Part 11 <sup>C)</sup>   | Consolidation and permeability tests in hydraulic cells with pore pressure measurement |
| Part 7               | Part 7, Part 8,<br>Part 10  | Shear strength tests (total stress)  |
| Part 8               | Part 9  | Shear strength tests (effective stress)  |
| – <sup>D)</sup>      | Part 6  | Fall cone  |

<sup>A)</sup> Not all parts of BS EN ISO 17892 were published at the time of publication of this British Standard. They are in preparation.

<sup>B)</sup> No equivalent in BS EN ISO 17892. The specific requirements for the tests are in each part of BS EN ISO 17892.

<sup>C)</sup> Partial equivalent in BS EN ISO 17892.

<sup>D)</sup> No equivalent in BS 1377.

Table 37 Common laboratory tests for soils (1 of 10)

| Category of test                            |             | Name of test or parameter measured                                    | Where details can be found     | Remarks   |
|---|-------------|---|--------------------------------|---|
| Classification tests<br>Head, 2006<br>[131] | Index tests | Water content (previously known as moisture content)                  | BS EN ISO 17892-1              | Generally carried out as a test on its own or with other tests. When carried out in conjunction with liquid and plastic limits (liquidity index or consistency index), it can give an indication of undrained strength.   |
|   |             | Liquid and plastic limits   | BS 1377-2 (BS EN ISO 17892-12) | Used to classify fine grained soil and the fine fraction of mixed soil. The derived value (plasticity index, $I_p$ ) is used with the percentage of less than 0.425 mm fraction to classify the swell and shrinkage (volume change) potential of clays. The relative consistency or liquidity index is calculated with water content and indicates consistency of the sample. With the clay-size proportion it can give an indication of the activity of the clay minerals. |
|   |             | Linear shrinkage  | BS 1377-2                      | An indicator of the shrinkage potential on desiccation.   |
|   | Density     | Particle density (previously known as specific gravity)               | BS 1377-2 (BS EN ISO 17892-3)  | Values reflect the proportions of different minerals present. It should be measured on samples used in compaction tests. Otherwise values commonly range between 2.55 Mg/m <sup>3</sup> and 2.75 Mg/m <sup>3</sup> . There are methods for fine-grained and for coarse grained soils. Many organic soils and some minerals might have particle densities very different to the values above.  |
|   |             | Bulk and dry density or unit weight                                   | BS EN ISO 17892-2              | Used in the calculation of forces exerted by soil. Dry density is used to calculate voids ratio, porosity and saturation.   |
|   |             | Limiting and relative density, maximum, minimum density index of sand | BS 1377-4                      | To identify the relative density of a coarse grained soil in comparison with the minimum and maximum density of that soil. Results can be used to indicate the stiffness and peak strength of coarse-grained soils. A number of different methods are available and need to be clearly identified as they are known to give different results on the same soils. The methods are sensitive to particle size distribution and particle shape.                                |

Table 37 Common laboratory tests for soils (2 of 10)

| Category of test                    |                        | Name of test or parameter measured   | Where details can be found       | Remarks  |
|-------------------------------------|------------------------|--|----------------------------------|--|
| Classification tests<br>(continued) | Particle size analysis | Coarse grained – sieving   | BS 1377-2<br>(BS EN ISO 17892-4) | Sieving methods give the grading of soil particles coarser than silt (<0.063 mm). When the sample contains silt or clay the test is done by wet sieving. The relative proportions of silt and clay are determined by means of sedimentation tests.   |
|                                     |                        | Fine-grained – sedimentation   | BS 1377-2<br>(BS EN ISO 17892-4) | Hydrometer or pipette analysis.  |
|                                     |                        | Automated methods primarily for fine grade   | Equipment manufacturer methods   | Automated methods including x-ray sedigraph, laser or granulometer methods are only to be used after they have been shown to give equivalent results as the standard methods. It is important to ensure that the sample sizes used are relevant for the particle sizes tested.   |
| Chemical tests                      |                        | Chemical tests for civil engineering purposes might be carried out in geotechnical laboratories. Most of the methods are described in BS 1377-3. These methods do not generally include modern analytical techniques. Analytical methods may be used if they are shown to give equivalent results to standard methods. The sample preparation should follow the methods in BS 1377-3 and the results reported as specified in this British Standard. |                                  |  |
|                                     |                        | pH value   | BS 1377-3                        | Measures the acidity or alkalinity of the soil or water. Needs to be performed as soon as possible after sampling. Values of pH might change during storage when pyrite oxidizes as the disturbed materials are exposed to the air. These materials are generally grey and dark grey clays and mudstones. It is often carried out in conjunction with sulfate tests. Excessive acidity or alkalinity of the groundwater in soils can have detrimental effects on buried concrete, cause corrosion of metals and use of resinous materials is unsuitable in alkaline soils. |

Table 37 Common laboratory tests for soils (3 of 10)

| Category of test           | Name of test or parameter measured                   | Where details can be found                                      | Remarks  |
|----------------------------|--|---|--|
| Chemical tests (continued) | Sulfate content of soils, rocks and groundwater      | BS 1377-3, BR279 [134], <i>TRL Report 447</i> [135]             | Groundwater containing dissolved sulfate ions can attack concrete and other cementitious materials placed in the ground or on the surface, and measurement of sulfate content allows classification of potential sulfate attack. See <i>BRE Special Digest 1</i> [N1] for guidance.<br>Sulfate extraction procedure as BS 1377-3 but the analysis might be by gravimetric, cation exchange, ion chromatography or ICP-AES. Results should be reported as SO <sub>4</sub> with units as required by BS 1377-3. Special procedures might be required when the samples come from contaminated sites and acidic, sulfate soils. BS 7755-3.11 (ISO 11048) also gives guidance on testing some contaminated soils for sulfate and is based on BR279 [134]. |
|                            | Total sulfur content of fine grained soils and rocks | BS 1377-3, BS 1047 or <i>TRL Report 447</i> [135]               | Measures the total sulfur content of soil (sulfate and sulfide) from which total potential sulfate is determined. For guidance see <i>BRE Special Digest 1</i> [N1].   |
|                            | Organic matter                                       | BS 1377-3   | The organic matter content can interfere with the hydration of Portland cement: cement pastes. Higher organic matter content might indicate greater compressibility and have an effect on plasticity values.<br>If modern analytical methods are used, such as total organic carbon analysers, the results should be presented as for the standard test method.  |
|                            | Mass loss on ignition                                | BS 1377-3   | Used as a measure of the organic content of peat or coarse soils with more than 10% organic matter. Not suitable for measuring the organic content of other soil types. Values might be affected by loss of the water of hydration from some minerals.   |
|                            | Carbonate content<br>Chemical methods                | BS 1377-3, Head, 2006 [131]                                     | Can be used as an index to assess the quality of chalk as a foundation. Higher carbonate content generally increases strength of rocks and soils and the removal of carbonate by weathering or alteration weakens the material. The carbonate of these rocks and soils might be used as an indicator of the degree of cementing and strength.  |
|                            | Analytical methods                                   | e.g. Thermal gravimetric analysis (TGA), Manufacturer's method. | Various analytical methods are available and can be used if they are shown to give similar results to the methods in this British Standard. Results should be presented as recommended in this British Standard.   |

Table 37 Common laboratory tests for soils (4 of 10)

| Category of test  | Name of test or parameter measured   | Where details can be found           | Remarks  |
|---|--|--------------------------------------|--|
| Chemical tests (continued)                              | Magnesium content of soils and groundwater   | Bowley, 1979 [136], BR279 [134]      | Can be used to supplement the sulfate content test to assess how aggressive soil or groundwater is to buried concrete. In the UK, raised levels of magnesium are generally only found in brownfield sites (see <i>BRE Special Digest 1</i> [N1]). Analytical methods may be used but the results should be reported in the same way as the method referenced here.   |
|   | Chloride content of soil and groundwater   | BS 1377-3                            | Can be used to indicate whether the soil, rock or groundwater is affected by saline water (e.g. sea water). Chloride in ground water causes corrosion of iron and steel.<br>Test recommended where pH of ground is less than 5.8. Results used in conjunction with sulfate and pH to assess the aggressiveness of the ground. Analysis by gravimetric, ion chromatography are in the standard but other methods may be used provided they give the same results. |
|   | Total dissolved solids in groundwater  | BS 1377-3                            | A general measure of salinity and indicative of aggressiveness of ground. Values related to electrical resistivity.  |
| Erodibility or dispersibility tests<br>Head, 2006 [131] | Some fine-grained soils are easily eroded and may be referred to as dispersive soils. This characteristic cannot be determined using classification tests. The erodibility and dispersibility tests might not identify all dispersive soils. |                                      |  |
|   | Pinhole test   | BS 1377-5, Head and Epps, 2011 [132] | Measures dispersibility of water flowing through a small hole.   |
|   | Crumb method   | BS 1377-5, Head and Epps, 2011 [132] | This qualitative test is used to classify the dispersive reaction of "crumbs" of clay in a weak solution of sodium hydroxide.  |
|   | Cylinder dispersion test   | Head and Epps, 2011 [132]            | This is an extension of the crumb method using a remoulded cylinder of soil is placed in a beaker and covered in an appropriate solution. The behaviour of the cylinder is noted after pore pressure equilibration.  |
|   | Dispersion or double hydrometer test   | BS 1377-5, Head and Epps, 2011 [132] | This test compares the particle size distribution of two identical representative specimens when one is tested with dispersant and mechanical mixing and the other without. The result is the ratio of the different clay size particles.  |
|   | Chemical test  | Head and Epps, 2011 [132]            | Determines the relative amount of sodium ions to the "total dissolved salts" (calcium, magnesium sodium and potassium) present in the pore water of the clay. The concentrations of the cations are determined using analytical methods. The percentage of sodium ions and the sodium absorption ratio (SAR) are calculated.   |

Table 37 Common laboratory tests for soils (5 of 10)

| Category of test                                      | Name of test or parameter measured   | Where details can be found                 | Remarks   |
|---|--|--|---|
| Soil corrosivity test<br>BS EN 13636,<br>ASTM G162-99 | Tests identify those soils and situations that are likely to corrode metal structures including iron and steel primarily in disturbed soil and man-made deposits. Tests are sensitive to sample oxidation. |  |   |
|   | Bacteriology   | BS 7361-1                                  | Undisturbed specimens required in sterilized containers and should be stored at about 4 °C.   |
|   | Redox potential  | BS 1377-3                                  | Measures the ability of the substrate to acquire electrons and, therefore, the tendency to reducing conditions.   |
|   | Resistivity  | BS 1377-3                                  | This test determines the electrical resistivity of sample of soil from which the corrosivity of a soil can be deduced.  |
| Compaction<br>Head, 2006 [131]                        | Water content/ dry density relationship  | BS 1377-4                                  | Indicates the degree of compaction that can be achieved at different water contents with different compactive effort: 2.5 kg, 4.5 kg or vibrating hammer.   |
|   | Moisture condition value (MCV),<br>Moisture Condition Calibration (MCC) test   | BS 1377-4                                  | The moisture condition value determines the minimum compactive effort required to produce near-full compaction. It is a rapid means of assessing the suitability of soil for use in control of earthworks construction. Interpretation might be difficult if particles are susceptible to crushing. The MCV/water content relationship (Moisture Condition Calibration) test is carried out over a range of water contents.       |
| Pavement design                                       | California bearing ratio   | BS 1377-4                                  | A penetrative test, generally on compacted samples to evaluate the strength of road sub-grade.  |
|   | Chalk crushing value (CCV)   | BS 1377-4,<br>Head, 2006 [131]             | Measures the resistance of chalk to crushing to assess its suitability as a fill material. Saturated lumps of chalk are subjected to the action of a free falling hammer within the MCV apparatus and the rate at which the lumps are crushed provides the chalk crushing value (CCV). In conjunction with the saturated water content of the intact lumps, it is used to classify the chalk use in freshly placed fill material. |
|   | Frost heave test   | BS 812-124<br>with notes<br>from BS 1377-5 | Assesses the susceptibility of compacted soil to frost heave.   |



Table 37 Common laboratory tests for soils (6 of 10)

| Category of test    |                          | Name of test or parameter measured  | Where details can be found     | Remarks   |
|---------------------|--------------------------|---|--------------------------------|---|
| Soil strength tests | Undrained shear strength | Undrained shear strength, $s_u$ , or cohesion, $c_u$ is a measure of strength without change in water content. Carried out on fine-grained materials. The information is used for assessing short term strength in a wide variety of design situations. |                                |   |
|                     |                          | Triaxial compression  | –                              | Triaxial tests are normally carried out on specimens with nominal diameters between 38 mm and 100 mm and with a height to diameter ratio of 2:1.  |
|                     |                          | Triaxial unconsolidated undrained compression   | BS 1377-7, (BS EN ISO 17892-8) | Preferably carried out on three specimens at different confining pressures. Single stage tests are used (see Head and Epps, 2011 [132]). Samples should be saturated and drainage is not allowed.   |
|                     |                          | Multistage Triaxial unconsolidated and undrained compression  | BS 1377-7                      | Multistage tests could be used where there is a shortage of test specimens. However, the results are not as reliable as the test above. The limitations of this test should be understood before this test is scheduled.  |
|                     |                          | Unconfined compression  | BS 1377-7, (BS EN ISO 17892-7) | A simple, rapid substitute for the unconsolidated undrained triaxial test. It is suitable only for saturated, non-fissured, fine grained soil.  |
|                     | Strength index tests     | Laboratory shear vane as defined by BS 1377-7   | BS 1377-7                      | Can be used on soft to firm fine-grained soils but is particularly suited to soft fine soils, as a strength index test. The samples remain in the sampling container or tube and so are not further disturbed. Sensitivity to remoulding can be assessed from the peak and remoulded strength tests. The results might be higher than other methods because a smaller volume is tested. |
|                     |                          | Fall cone   | BS EN ISO 17892-6              | Provides an indication of the undrained shear strength on very soft and soft fine-grained soils.  |

Table 37 Common laboratory tests for soils (7 of 10)

| Category of test                   |   | Name of test or parameter measured   | Where details can be found    | Remarks  |
|------------------------------------|---|--|-------------------------------|--|
| Soil strength tests<br>(continued) | Effective stress tests<br>Head and Epps, 2013 [133] | The effective strength tests take into consideration pore pressures or are carried out at a rate to ensure that there is no or very little change in pore pressures (drained tests).<br>Data from effective strength tests are used for the analysis of long-term stability in a variety of design situations. |                               |  |
|                                    |   | Triaxial compression tests   | Head and Epps, 2013 [133]     | The consolidation is usually isotropic but anisotropic consolidation might be appropriate in some circumstances.   |
|                                    |   | Triaxial consolidated undrained test with pore pressure measurements.  | BS 1377-8, BS EN ISO 17892-9  | The sample is saturated and consolidated prior to compression. The rate of compression needs to be slow enough to allow pore pressures to equalize during compression. Local strain gauges or pore pressure sensors allow more accurate measurements.  |
|                                    |   | Triaxial consolidated drained test with measurements of volume change  | BS 1377-8, BS EN ISO 17892-9  | Samples are saturated, consolidated and the rate of compression set so there is little rise in pore pressure. The sample is allowed to drain during the test. In low permeability materials long periods are needed to dissipate excess pore pressures during compression.   |
|                                    |   | Multistage triaxial versions of a) and b)  | BS 1377-8                     | Multistage tests might be useful where there is a shortage of test specimens. Results are not as reliable as single stage tests.   |
|                                    |   | Triaxial Stress path tests   | Head and Epps, 2013 [133]     | Stress path tests can be applied to tests b) and c) to reproduce the stress history of the ground before and during construction.  |
|                                    |   | Direct shear (shear box)   | BS 1377-7, BS EN ISO 17892-10 | An alternative to triaxial tests. Disadvantages are: drainage conditions cannot be controlled nor pore pressures measured and the plane of shear is predetermined by the nature of the test. An advantage is that samples of coarse-grained soil can be more easily prepared than in the triaxial test. Only drained tests should be undertaken. Shear boxes are normally square with sides of 60 mm or 100 mm but can also be circular in plan. For gravels shear boxes with sides 300 mm or larger should be used. |

Table 37 Common laboratory tests for soils (8 of 10)

| Category of test                                    |                   | Name of test or parameter measured                           | Where details can be found                                     | Remarks   |
|---|-------------------|--|--|---|
| Soil strength tests<br>(continued)                  | Residual strength | The residual strength of a fine soil that has already failed |  |   |
|   |                   | Ring shear test  | BS 1377-7,<br>BS EN ISO 17892-10                               | This is the preferred method as large strains can be used to induce a shear plane and continue to a minimum residual shear strength. The failure envelope is not a straight line particularly at low normal stresses.   |
|   |                   | Multiple reversal shear box                                  | BS 1377-7,<br>BS EN ISO 17892-10                               | Many reversals might be required for the strain required to obtain the residual strength. Each test stage might require several days.   |
|   |                   | Shear box test performed on a shear surface                  | BS 1377-7  | Aligning the shear plane can be difficult as an accurate estimate of consolidation is required before shearing to ensure that the movement is along the shear plane.  |
| Soil deformation tests<br>Head and Epps, 2011 [132] |                   | One-dimensional compression and consolidation tests          | BS 1377-5,<br>BS EN ISO 17892-5                                | Measure soil parameters coefficient of volume change, $m_v$ , and coefficient of consolidation, $c_v$ , for simple calculations of the magnitude and rate of settlement of foundations respectively. Reasonable assessments of the magnitudes of foundation settlements can be made if Class 1 samples are tested. The voids ratio vs. log normal stress graph can be used to determine the yield stress (previously known as the preconsolidation stress). Estimates of settlement can be much improved if small strain triaxial and pressure meter tests are used. Estimates of the rate of settlements have been found to be highly inaccurate with certain types of soil. |
|   |                   | Standard oedometer (incremental loading)                     | BS 1377-5,<br>BS EN ISO 17892-5                                | The standard dead weight loading oedometer is that in general use.  |
|   |                   | Hydraulic oedometer (Rowe cell)                              | BS 1377-5  | The alternative is the hydraulic oedometer (Rowe cell) in which the vertical loading and the pore pressures can be independently controlled.  |
|   |                   | Continuous loading oedometer tests                           | Head and Epps, 2011 [132],<br>Atkinson and Davison, 1990 [137] | Instead of applying the loads in discrete increments, as in the standard test, stresses, strains or pore pressures may be varied continuously.  |
|   |                   | Collapse on wetting  | BS 1377-5  | Determines the settlement on saturation, so-called collapse test. Fine soils with an open structure might be prone to collapse on loading and saturation, such as some loessic deposits and red tropical residual soils.  |

Table 37 Common laboratory tests for soils (9 of 10)

| Category of test                                | Name of test or parameter measured  | Where details can be found                             | Remarks  |
|---|---|--|--|
| Permeability tests<br>Head and Epps, 2011 [132] | Laboratory permeability tests often yield results of limited value and in-situ tests are generally thought to yield more reliable data. |  |  |
|   | Constant head test  | BS 1377-5,<br>BS EN ISO<br>17892-11                    | The constant head test is suited only to soils of permeability normally within the range $10^{-5}$ m/s to $10^{-2}$ m/s, i.e. coarse soils. Test materials should be at the required density.  |
|   | Falling head test   | BS EN ISO<br>17892-11,<br>Head and Epps,<br>2011 [132] | The falling head test is applicable to soils with a permeability range of $10^{-9}$ m/s to $10^{-5}$ m/s, such as silt and some clays. Undisturbed, remoulded or compacted samples may be used. Samples that swell during test might not give reliable results.  |
|   | Falling head with oedometer   | Head and Epps,<br>2011 [132]                           | For soils of permeability of $10^{-11}$ m/s to $10^{-9}$ m/s such as clays, an adapted oedometer cell may be used.   |
|   | Hydraulic oedometer (Rowe cell)   | BS 1377 (all parts),<br>Head and Epps,<br>2013 [133]   | Rowe consolidation cell allows the direct measurement of permeability under constant head with a back pressure and confining pressures more closely consistent with the field state. The Rowe cell allows either vertical or radial flow. Undisturbed or remoulded samples may be used.  |
|   | Triaxial constant head permeability test  | BS 1377-6,<br>Head and Epps,<br>2013 [133]             | Measurements on a saturated and consolidated specimen under known effective stress condition, which use a constant head pressure difference between the top and base of the test specimen and measure the volume change to calculate the rate of fluid flow. This requires two back pressure systems to maintain the constant head.                  |
|   | Triaxial falling head permeability  | Head and Epps,<br>2013 [133]                           | Uses a triaxial cell with one or both of the back pressure systems replaced by a burette. This does not allow for the saturation of the sample.  |
|   | Triaxial permeability of low permeability soils   | Head and Epps,<br>2013 [133]                           | Measurements in low permeability soils using pore pressure transducer or mercury null indicator. The sample is saturated and consolidated prior to test.   |
|   | Triaxial permeability test with a constant flow rate for low permeability soils   | Olsen, Nichols and Rice, 1985 [138]                    | Generally used on very low permeability soils of less than $10^{-9}$ m/s. This triaxial test uses a constant flow rate and constant back pressure. The pressures produced by the constant flow rate should not be so high as to greatly alter the effective stress conditions. The pumped flow rate might be very low requiring sophisticated pumps. |

Table 38 Swelling and shrinkage tests (10 of 10)

| Category of test            | Name of test or parameter measured  | Where details can be found                    | Remarks   |
|-----------------------------|---|---|---|
| Shrinkage and swelling test | There are a number of tests that can be used to understand the shrinkage and swelling characteristic of clays and extremely weak to weak mudstone. These tests are commonly identified as soil or rock tests; however, many of the tests can be carried out on both material types. |   |   |
|                             | Shrinkage limit test  | BS 1377-2, Hobbs et al., 2013 [139]           | An indication of the minimum water content below which there is no significant shrinkage. This test is carried out using mercury (BS 1377-2). Because of the use of this poisonous liquid and the practical difficulties of this method it is very rarely carried out in the UK. New apparatus has been developed to carry out this test using laser range finding techniques and does not use mercury. |
|                             | Swelling strain index for radially confined specimens with axial surcharge  | BS 1377-5, BS EN ISO 17892-5, ISRM, 2007 [55] | Measures the axial swelling strain developed against a constant axial pressure or surcharge, when radially confined.<br>This test may be carried out in a standard oedometer or using an oedometer cell.  |
|                             | Constant volume swell pressure  | BS 1377-5, BS EN ISO 17892-5, ISRM, 2007 [55] | Results are used to identify if the ground beneath a foundation load might swell with increasing water content. This test is done using the standard oedometer by adding weight to negate any swell strain; automated systems are available.  |
| Soil suction                | Three-dimensional swelling strain   | ISRM, 2007 [55]                               | The standard apparatus is unsuitable for tests on samples that deteriorate or slake in water. An alternative apparatus, which can test firm and stiffer clay and rocks, is currently being developed.   |
|                             | To assess negative pore pressures (soil suction) which provides information on volume change, deformation and strength characteristics of fine soil.  |   |   |
|                             | Suction plate   | Manufacturer's instructions                   | The different ceramic plates used allows the measurement of suctions generally in the range of 10 kPa to 1500 kPa. This method is more often used in soil science.  |
|                             | Filter paper  | BRE IP4/93 [140], ASTM D5298-10               | The filter paper method has a range from 10 kPa to 100 000 kPa.   |

Table 39 Specialist laboratory tests for soils (1 of 2)

| Category of test     | Name of test or parameter measured  | Where details can be found                    | Remarks   |
|----------------------|---|---|---|
| Shear strength       | Simple direct shear   | ASTM D6528-07, Bjerrum and Landva, 1966 [141] | Determination of lateral shear strength and stress-strain parameters measured under plane strain and constant volume conditions, simulating undrained conditions for a saturated specimen. The principle stresses rotate during the application of the shear stress, simulating a number of design situations (e.g. axial loading of piles).  |
| Cyclic soils testing | Cyclic triaxial testing modulus and damping properties of soils<br>Load controlled cyclic triaxial strength of soil | ASTM D3999-11, ASTM D5311-11                  | Determination of the cyclic shear modulus, G, and damping characteristics of soils at intermediate and high strain levels. These might be relevant to dynamic, linear and non-linear analytical methods and performance evaluation of structures under dynamic or cyclic loads such as caused by earthquakes, ocean waves, or blasting. Measures reduction of shear strength as a result of cyclic loading, including liquefaction potential of soils. Test options include drained or undrained conditions, stress or strain control, and the required frequency, wave-form and amplitude of the cyclic excitation in order to model the stress that the in-situ soil experiences. The test conditions need to be carefully designed and monitored. These are expensive and highly sensitive tests and the advice of an expert in these tests is recommended to ensure that the cyclic stress expected on or in the ground is being modelled correctly in the laboratory specimen. |
|                      | Modulus and damping of soils by resonant column   | ASTM D4015-07                                 | Determination of small strain shear stiffness (G) and its degradation with respect to shear strain. The test is also used to determine material damping characteristics. Some test instruments also allow a torsional shear of the samples. Note that the measured resonant frequency relates only to the test specimen at its test condition, and is not representative of the resonant frequency of the in-situ bulk soil horizon.  |

Table 39 Specialist laboratory tests for soils (2 of 2)

| Category of test                    | Name of test or parameter measured          | Where details can be found                         | Remarks  |
|-------------------------------------|---|--|--|
| Cyclic soils testing (continued)    | Cyclic simple shear tests                   | ASTM D6528-07, Andersen, Kleven Heien, 1988 [142]  | Degradation of shear strength, and liquefaction potential, with cyclic stress in the lateral plane.<br>Tests options include drained or undrained conditions, stress or strain control, and the required frequency, wave-form and amplitude of the cyclic excitation in order to model the stress that the in-situ soil experiences.<br>In all tests, the conditions need to be carefully designed and monitored. These are expensive and highly sensitive tests and the advice of an expert in these tests is recommended to ensure that the cyclic stress expected on the ground is being modelled correctly in the laboratory specimen. |
| Strength tests on unsaturated soils | Triaxial tests on unsaturated soils.        | For instance Leong, Byunt and Rahardjo, 2013 [143] | Tests require both pore pressure and air pressure measurement. Used where the behaviour of partially saturated soil is important to design.  |
| Permeability on unsaturated soils   | Hydraulic conductivity of unsaturated soils | ASTM D7664-10                                      | Measurement of hydraulic conductivity of unsaturated soils. Measures either the relationship between hydraulic conductivity and matrix suction or that between hydraulic conductivity and volumetric water content, gravimetric water content, or degree of saturation. Applicable where the permeability of unsaturated soils is important to design.   |

Table 40 Rock testing (1 of 3)

| Category of test                                      | Name of test or parameter measured   | Where details can be found          | Remarks  |
|---|--|-------------------------------------|--|
| Rock classification                                   | Petrographic description   | ISRM, 2007 [55]                     | Identification of the rock type, grain size and texture, nature of cements and bonding, degree of weathering, estimates of pore size and shape.  |
| Rock classification tests                             | Natural water content  | ISRM, 2007 [55]                     | The natural water content of rock can usually only be measured on good quality undisturbed core that has been preserved so it does not lose water.   |
|   | Saturated water content<br>Bulk density<br>Water content<br>Porosity<br>Particle density | ISRM, 2007 [55]                     | These parameters could be related to other parameters such as compressive strength, modulus of elasticity, seismic wave velocity and degree of weathering.   |
|   | Slake durability   | ISRM, 2007 [55]                     | Useful index for testing rocks proposed for construction materials. Assesses the resistance offered by a rock to weakening and disintegration when subjected to two standard cycles of drying and wetting. More cycles might be applicable.  |
|   | Hardness and abrasiveness  | ISRM, 2007 [55]                     | Gives an indication of the potential wear of machinery involved in rock cutting, breaking and crushing.<br>Hardness tests include indentation tests such as Brinell and Rockwell tests, dynamic rebound – shore scleroscope and scratch tests. Abrasiveness tests include the Los Angeles and Cerchar tests.   |
| Characterization of pore volume and pore throat sizes | Mercury porosimeter  | ISRM, 2007 [55]<br>ASTM<br>D4404-10 | Measures the size of pores in rocks. Helium porosimetry has a lower pore throat size limit than mercury porosimetry. Samples are dried before the test, this might change the pore and the pore throat size for example in rocks that change volume on drying, e.g. some mudstones or sandstones that contain clay pore linings that collapse on drying. |
|   | Helium porosimeter   | API, 1998 [144]                     |  |



Table 40 Rock testing (2 of 3)

| Category of test    | Name of test or parameter measured   | Where details can be found   | Remarks  |
|---------------------|--|--|--|
| Rock strength tests | Schmidt hammer   | ISRM, 2007 [55]  | Provides an indirect measurement of compressive strength of weak and stronger rocks. It is generally used in the field but may be used in the laboratory. A number of tests are carried out to find the average value. Laboratory tests may be carried out on boulders or core.  |
|                     | Point load test  | ISRM, 2007 [55]<br>ASTM<br>D5731-08  | A simple field and laboratory compressive strength test that can be carried out on core or blocks. It is a useful aid to core logging. Various published papers have provided corrections to estimate the unconfined compressive strength from corrected point load test values; the correction might depend on rock type.   |
|                     | Uniaxial compressive strength  | ISRM, 2007 [55],<br>ASTM<br>D4543-08,<br>ASTM<br>D7012-10  | Carried out on intact samples with no discontinuities to characterize the material properties of a rock sample. The length to diameter ratio is a minimum of 2:1 for cylinders. Tests should be at a suitable water content or saturation for the engineering situation.<br>Machining samples to the specified tolerances is likely to require specialist equipment. |
|                     | Tensile strength tests   | Rock is much weaker in tension than in compression. The tensile strength may be used to determine the failure condition for the rock material. |  |
|                     | Direct tensile strength test   | ISRM, 2007 [55],<br>ASTM<br>D4543-08,<br>ASTM<br>D2936-08  | Determines the direct tensile strength of intact cylindrical rock specimen.  |
|                     | Indirect tensile strength (Brazilian disc or splitting tensile strength)                           | ISRM, 2007 [55],<br>ASTM<br>D3967-08   | A simple, inexpensive measurement of the tensile strength using compressive stresses. The test requires the disc specimen to break diametrically between the platen contacts due to tensile pulling along the loading diameter. A rock or concrete press may be used to provide the compression stress.  |
|                     | Triaxial compression:<br>a) Undrained<br>b) Undrained with pore pressure measurement<br>c) Drained | ISRM, 2007 [55],<br>ASTM<br>D4543-08,<br>ASTM<br>D7012-10  | Usually carried out on intact samples with no discontinuities to provide data on rock material properties. Undrained tests might be tested dry, whereas undrained tests with pore pressure measurements and drained test are carried out on saturated specimens. A number of tests are tested at different confining or effective stresses.                          |

Table 40 Rock testing (3 of 3)

| Category of test            | Name of test or parameter measured  | Where details can be found                          | Remarks  |
|-----------------------------|---|---|--|
| Fracture toughness          | Used for classification of rock material as an index of fragmentation process such as tunnel boring and model blasting and modelling rock fragmentation of rock cutting, hydraulic fracturing, radial explosive fracturing and other similar situations.<br>There are a wide variety of specimen types and methods and the values are generally not comparable. The methods given here are those suggested by the International Society for Rock Mechanics in an attempt to increase standardization. |   |  |
|                             | Chevron bend test<br>Short rod test<br>Chevron notched<br>Brazilian disc test   | ISRM, 2007 [55]                                     | Uses a rock core with a V-shaped notch cut. There are two levels of testing; level 1 requires the recording of the maximum load, whilst level 2 requires continuous load and displacement measurement during the test. The chevron bend and Brazilian disc tests use compressive loads on three rollers, whereas the short rod test uses tensile loads.<br>The Brazilian disc test might be used to investigate full rock anisotropic fracture toughness.  |
| Discontinuity strength test | Direct shear box  | ISRM, 2007 [55],<br>ASTM D5607-08                   | Measures the strength of rock discontinuities such as joints, shear surface or gouge. The values are used in the assessment of the behaviour of the rock mass.   |
| Rock deformation tests      | Static elastic moduli<br>Uniaxial<br>Triaxial   | ISRM, 2007 [55],<br>ASTM D4543-08,<br>ASTM D7012-10 | Strain gauges, extensometers or other suitable measuring devices may be used. See remarks on uniaxial compressive tests.   |
|                             | Creep tests – Constant load<br>a) Undrained<br>b) Constant load/stress and temperature<br>c) Triaxial   | ISRM, 2007 [55],<br>ASTM D4543-08,<br>ASTM D7070-08 | Measures the strain under constant load under uniaxial or triaxial conditions and at a constant temperature. Used in the long term stability analysis of underground structures. Most meaningful when carried out under multi-stress conditions.   |
| Rock permeability           | Measures the permeability of rock   |   |  |
|                             | Flexible wall permeameter   | ASTM D5084-10                                       | The test methods apply to one-dimensional, laminar flow of water. It is applicable to both soil and rock although the test equipment is different. This test requires the sample to be saturated. Permeability with respect to other liquids may be measured using similar methods. The hydraulic conductivity is carried out at a controlled level of effective stress. The relationship between the hydraulic conductivity and voids ratio can be assessed using different effective stresses. |
|                             | Flowing air   | ASTM D4525-08                                       | Measures the permeability to air of a small sample of rock. By extrapolation, it is used to determine an equivalent of the liquid permeability. This parameter is used to calculate the flow through rock of fluids subjected to a pressure differential.  |

Table 41 Tests for aggregate suitability

| Category of test | Name of test or parameter measured               | Where details can be found  | Remarks   |
|------------------|--|---|---|
| Aggregate tests  | General properties of aggregates                 | BS EN 932-1,<br>BS EN 932-3,<br>BS EN 932-5,<br>BS EN 932-6   | Includes methods of sampling, terminology for simplified petrographic description, common equipment and calibration and definitions of repeatability and reproducibility.   |
|                  | Tests for geometrical properties of aggregates   | BS EN 933-1,<br>BS EN 933-3,<br>BS EN 933-4,<br>BS EN 933-5,<br>BS EN 933-6,<br>BS EN 933-7,<br>BS EN 933-8,<br>BS EN 933-9,<br>BS EN 933-10,<br>BS EN 933-11 | Includes determination of particle size distribution, sieves, particle shape – flakiness index and shape, percentage of crushed and broken surfaces in coarse aggregate particles, percentage of shells in coarse aggregates, assessment of fines – methylene blue (methylthioninium chloride), grading of filler aggregates and classification test for the constituents of coarse recycled aggregate.         |
|                  | Mechanical and physical properties of aggregates | BS EN 1097-1,<br>BS EN 1097-2,<br>BS EN 1097-3,<br>BS EN 1097-4,<br>BS EN 1097-5,<br>BS EN 1097-7,<br>BS EN 1097-8,<br>BS EN 1097-9,<br>BS EN 1097-10,        | Includes the determination of resistance to wear (micro-Deval), methods for the determination: of resistance to fragmentation, loose bulk and voids, voids to dry compacted filler, water content by drying in a ventilated oven, particle density and water absorption, particle density of filler Pyknometer method, polished stone value, wear and abrasion form studded tyres – Nordic test, water suction. |
|                  | Thermal and weathering properties of aggregates  | BS EN 1367-1,<br>BS EN 1367-2,<br>BS EN 1367-3,<br>BS EN 1367-4,<br>BS EN 1367-5,<br>BS EN 1367-6   | Includes determination of: resistance to freezing and thawing, magnesium sulfate test, boiling test Sonnenbrand basalt, drying shrinkage, resistance to thermal shock, resistance to freezing and thawing in the presence of common salt (NaCl).  |
|                  | Chemical properties of aggregates                | BS EN 1744-1,<br>BS EN 1744-3,<br>BS EN 1744-4,<br>BS EN 1744-5,<br>BS EN 1744-6  | Includes chemical analysis, preparation of eluates by leaching of aggregates, water susceptibility of fillers for bituminous mixtures, acid soluble chloride salts, influence of recycled aggregate extraction on the initial setting time of cement.   |

Table 42 Geophysical laboratory tests (1 of 2)

| Category of test   | Name of test or parameter measured   | Where details can be found   | Remarks  |
|--------------------|--|--|--|
| Thermal properties | <p>Consideration should be taken as to whether the temperatures used change the mineralogy or degrade the test specimen.</p> <p>The data are used or considered in design where the temperature of the ground changes for instance underground stores of thermogenic nuclear waste, compressed gas, and underground power stations. Thermal properties, other than linear expansion, are also used in the assessment of underground thermal storage (ground source heat pumps and thermal piles) and solar storage facilities.</p> <p>Thermal diffusivity = thermal conductivity / (density × specific heat capacity).</p> |  |  |
|                    | Linear thermal expansion (rocks)   | <p>Linear expansion is the change in dimension per unit change in temperature.</p> <p>Thermal strain might cause thermal stress that could affect stability of underground excavations.</p> <p>Linear expansion is more commonly measured using a dilatometer.</p> |  |
|                    | Dilatometer method   | ASTM E228-11   | This method covers the determination of the linear thermal expansion of rigid solid materials using push-rod dilatometers.   |
|                    | Strain gauge method  | ASTM D5335-08  | This test method is based on continuously monitoring thermal strain as a function of temperature and also, how the coefficient of linear thermal expansion changes with temperature. It uses bonded electric resistance strain gauges on intact rock cores and is applicable for unconfined stress states over the temperature range from 20 °C to 260 °C. Test specimens might be saturated, dry or partially saturated. For saturated or partially saturated specimens test temperatures should be at least 10 °C less than the boiling point of the saturating fluid. |
|                    | Other methods  | BS EN ISO 10545-8<br>ASTM E831-14  | Both methods are applicable for samples that remain solid over the temperature range used.   |
|                    | Specific heat capacity   | ASTM D2766-95  | The specific heat or heat capacity is a measure of the amount of energy required to produce a given temperature change within a unit quantity of that substance. It is used in engineering calculations that relate to the manner in which a given system might react to thermal stresses and storage. For dry samples the effect of water content, saturation and porosity of the in-situ material should be taken into account when applying the results.  |
|                    | Specific heat of soil and rock   | ASTM D4611-08  | This method covers the determination of instantaneous and mean specific heat of rock and soils. This method is limited to dry samples.   |

Table 42 Geophysical laboratory tests (2 of 2)

| Category of test   | Name of test or parameter measured   | Where details can be found   | Remarks   |
|--|--|--|---|
| Thermal properties (continued)                                       | Thermal conductivity   |  | Thermal conductivity is the transport of energy, in the form of heat, through a body of mass as the result of a temperature gradient. The effect of water content, saturation and porosity of the in-situ material has to be taken into consideration when applying the results.<br>It is also used in the analysis and design of underground transmission lines and oil and gas pipelines.<br>Thermal diffusivity = thermal conductivity / (density x specific heat capacity). |
|  | Soils and weak rock<br>Thermal probe method  | ASTM D5334-08  | Determines the thermal conductivity using a transient heat method and is applicable to soil and very weak rocks.  |
|  | Rock<br>Guarded-comparative-longitudinal heat flow method  | ASTM E1225-13  | Describes a steady state technique for determining the thermal conductivity. The method is applicable to materials with effective thermal conductivities in the range of 0.2 W/m.K to 200 W/m.K.  |
| Electrical resistivity   | Electrical resistivity is used to assess corrosion of underground structures and to aid the modelling and understanding of field resistivity measurements. The values of resistivity depend on a number of factors including porosity, saturation, pore fluid resistivity, clay content of the sample and temperature.   |  |   |
|  | Galvanic soil  | BS 1377-3,<br>ASTM G187-12   | Carried out on undisturbed or remoulded soil samples.   |
|  | Rock   | Equipment manufacturer's or in-house methods   | Resistivity of rock samples in the laboratory are not normally higher than the rock mass which can be influenced by discontinuities. Induced polarization values determined in the laboratory are less affected.  |
|  | Inductive (non-contacting)   | Equipment manufacturer's methods   | This method is used in some laboratory geophysical core logging equipment. This method is applicable to both soil and rock. This method is more effective on materials with lower electrical resistivities.   |
| Seismic velocity, small strain stiffness and dynamic elastic modulae | Seismic velocity, p-wave (primary, longitudinal or compressional wave) velocity and s-wave (secondary, transverse or shear wave) velocity with density values are used to calculate the dynamic elastic moduli. They are also used to compare with field values to assess rock mass characteristics. Tests can be carried out under uniaxial or triaxial conditions. Values are usually higher than static elastic moduli. |  |   |
|  | P-wave or sonic velocity   | ISRM, 2007 [55],<br>ASTM D2845-08  | The laboratory P-wave velocity is used as a classification test. Piezoelectric transducers are usually used to produce and receive the P-waves.   |
|  | S-wave or shear wave velocity using bender elements (soils and weaker rocks)   | Dyvik and Madshus, 1985 [145]<br>Dyvik and Olsen, 1989 [146]<br>Leong, Yeo and Rahardjo, 2005 [147]<br>Santamarina, Klein and Fam 2001 [148] | Measurement of shear wave velocities and hence small strain shear modulus in soils, and damping characteristics. Very short bender elements can be used on weaker rocks. Measurements can be made under uniaxial or triaxial conditions. Results are sensitive to the test conditions and effective stress in triaxial tests.<br>Bender elements can be mounted axially or radially on a specimen, Tests can be configured to measure stiffness anisotropy.                     |

## Section 10: Reports and interpretation

### 62 General

High quality records and data should be generated, collated and passed on, as these form a fundamental part of the geotechnical design.

*NOTE 1 Ground investigation works can be undertaken in a number of phases and the precise details of the development might not be fully defined in early phases.*

The data generated from the ground investigation should be put into a format which allows data communication between all parties and data manipulation at various stages throughout the life of the works (see BS 8574 for guidance).

*NOTE 2 A suitable protocol for management and transfer of digital data is provided by the AGS and is known as "AGS format".<sup>15)</sup>*

All reports should be prepared in accordance with the requirements of BS EN 1997-1 and BS EN 1997-2 and the related test standards under which the work is carried out. Any additional reporting requirements should be identified in the contract specification. In accordance with BS EN 1997-1 and BS EN 1997-2, two separate reports should be prepared – a Ground Investigation Report (GIR) and a Geotechnical Design Report (GDR).

The GIR should present the factual information and assess and interpret the available information; this might include derivation of parameters from the test results.

The GDR should present the characteristic and design values, the calculations to verify the safety and serviceability of the geotechnical structure together with identification of the items to be checked during construction, and the supervision, monitoring and maintenance requirements.

*NOTE 3 BS EN 1997 does not specify who is required to produce either these reports or their constituent parts. Although a number of parties are likely to prepare separate parts, a party or parties need to be identified and appointed to collate the whole report. For example, a ground investigation contractor might be commissioned to undertake and produce a factual report on intrusive works (i.e. exploratory holes), monitoring and laboratory testing, but not to carry out or report on the desk study or field reconnaissance which are constituents of the GIR. There is no reason why the responsibility for compiling the GIR and GDR cannot be carried out by different parties.*

The GIR and GDR should remain as live documents throughout the investigation process; this includes the incorporation of the results of investigations both during construction and after construction is complete and the structure is in operation. The party responsible for this on-going compilation should be identified in the relevant contract documents.

Reports on integrated investigations (i.e. those in which geotechnical investigation is carried out in parallel with those into other aspects of the site – see 17.8) should conform to the guidance presented here and any authoritative guidance covering the other aspect(s). In particular, reports on the contamination aspect of a site should be in accordance with BS 10175 and those referring to ground gas should be in accordance with BS 8576. Information may be provided in a combined report(s) or in separate reports.

*NOTE 4 Planning conditions often require that investigations and reporting are carried out in accordance with BS 10175. Failure to comply with the requirements in BS 10175 and BS 8576 regarding reporting might, therefore, cause delays in the consideration of a planning application or possibly rejection of a report.*

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<sup>15)</sup> See <<http://www.ags.org.uk>> [last viewed 24 June 2015].

All reports should meet the requirements of BS EN 1997-1 and BS EN 1997-2. The report and data should be passed on to the construction team and sub-contractors as required.

*NOTE 5 The reporting requirements of BS EN 1997 are summarized in Table 43 where they are separated into general items that are required in all reports and then the field and laboratory reports and the GIR and the GDR respectively.*

Table 43 Summary of reporting requirements (1 of 5)

| Report   | Section                     | Descriptive items to be included   |
|--|-----------------------------|--|
| All reports  | General information         | <ul style="list-style-type: none"> <li>Name of owner/client of the site and the proposed structure</li> <li>Names of all consultants, contractors and sub-contractors</li> <li>Location of site referenced to a national or site grid reference</li> <li>Proposed works/development</li> <li>Geotechnical category of the proposed structure</li> <li>Purpose and scope of the geotechnical investigation</li> <li>Title of the investigation and report number</li> </ul>   |
| Ground Investigation Report (GIR)<br>[BS EN 1997-1: 2004+A1:2013, 3.4; BS EN 1997-2: 2007, Clause 6] | Desk study report           | <ul style="list-style-type: none"> <li>Description of site history</li> <li>Collation and interpretation of previous ground investigations</li> <li>Expected geology of the site including faulting</li> <li>Expected hydrogeology and hydrology of the site</li> <li>Available survey information</li> <li>Information from aerial photographs and other sources of remote sensing</li> <li>Local experience of the area</li> <li>Topography/geomorphology</li> <li>Potential for mining and natural cavities</li> <li>Potential presence of hazards such as UXOs or contamination</li> <li>Information about the seismicity</li> <li>The current ground model</li> </ul> |
|  | Field reconnaissance report | <ul style="list-style-type: none"> <li>Description of site, its topography and surroundings</li> <li>Evidence of surface water and groundwater</li> <li>Presence of structures on the site and in the neighbouring area and their condition</li> <li>Exposures in the vicinity including natural exposures, quarries, cuttings and borrow areas</li> <li>Areas of stability or instability</li> <li>Photographs of the site and surrounding areas</li> <li>The current ground model</li> <li>Presence of existing piezometers or wells and any measurements taken</li> <li>Presence of trees and their type and other vegetation</li> </ul>                                |

Table 43 Summary of reporting requirements (2 of 5)

| Report | Section  | Descriptive items to be included   |
|--------|--|--|
|        | Field reports including investigation holes, sampling and groundwater measurements<br>[See also BS EN ISO 22475-1: 2006, Section 12] | <ul style="list-style-type: none"> <li>• Summary logs of all exploratory holes including, as appropriate, drilling records, sampling records, soil and rock identification, backfilling records, installation records and groundwater measurements</li> <li>• Numbering of the investigation points including boreholes, trial pits, sampling and measurement positions</li> <li>• Location of investigation holes related to national or site grid</li> <li>• Ground levels at all investigation positions related to national, project or site datum</li> <li>• The orientation of all investigation holes</li> <li>• Observations on the weather conditions during the fieldwork period</li> <li>• Difficulties during excavation or construction of investigation holes including progress, stability</li> <li>• Types and sizes (diameters and changes in diameter) of field equipment used to form investigation holes</li> <li>• Compiled record logs of all borehole and trial excavation holes based on field descriptions including depths to the top of each stratum and its thickness</li> <li>• Core recoveries (total) for all core runs and fracture state (solid core recovery, rock quality designation and fracture index in rock); identification of all zones of core loss</li> <li>• Details of all samples or cores taken including type, depth and method of insertion</li> <li>• Procedures used for sampling, transport and storage of samples</li> <li>• Details of all tests carried out including type, depth and results</li> <li>• Calibration certificates and reference numbers for test equipment in use</li> <li>• Data on water strikes, levels at each sample and test and overnight, and any fluctuations of water level during the field work period</li> <li>• Details of any water or other fluid added to the investigation hole to aid boring or as flush, including colour and proportion of returns</li> <li>• Observations on surface and ground water</li> <li>• Details of backfilling of investigation holes and of instruments installed (type and depths of the construction, confirmation of correct functioning)</li> <li>• Readings from instrumentation during the field work period</li> <li>• Tabulation of quantities of field work</li> <li>• Presentation of field observations made by field personnel during the investigation activities</li> <li>• Photographs of samples, cores, faces and spoil as appropriate</li> <li>• Plans with survey data showing the structure and location of all investigation and sampling points</li> <li>• Name and signature of the Responsible Expert</li> </ul> |



Table 43 Summary of reporting requirements (3 of 5)

| Report | Section                 | Descriptive items to be included  |
|--------|-------------------------|---|
|        | Field test report       | <ul style="list-style-type: none"> <li>• Results of all field tests presented and reported according to the requirements defined in the EN or BS standards applied</li> <li>• Certification and calibration documentation</li> <li>• Tabulation of quantities of field work</li> <li>• Name and signature of the Responsible Expert</li> </ul>  |
|        | Laboratory test reports | <ul style="list-style-type: none"> <li>• Results of all laboratory tests presented and reported according to the requirements defined in the EN or BS standards applied and other standards or methods as applicable</li> <li>• Certification and calibration documentation</li> <li>• Tabulation of quantities of laboratory work</li> </ul>   |
|        | Other reports           | <ul style="list-style-type: none"> <li>• Any other reports not included above such as:</li> <li>• Reconnaissance geophysical surveys</li> <li>• Probe records such as DP (dynamic probe) or CPT</li> <li>• Specialist testing reports such as plate load tests</li> <li>• Geophysical testing reports, from the surface or using boreholes for access below the surface</li> <li>• Specialist sampling such as block samples</li> <li>• Contamination surveys and chemical testing</li> <li>• Gas monitoring reports</li> </ul> |
|        | Factual report          | <ul style="list-style-type: none"> <li>• Account of all field and laboratory work</li> <li>• Photographs of the field and laboratory work</li> <li>• Documentation of the methods used to carry out the field investigations and laboratory testing</li> <li>• Dates between which field and laboratory work was carried out</li> </ul>   |

Table 43 Summary of reporting requirements (4 of 5)

| Report   | Section                             | Descriptive items to be included  |
|--|-------------------------------------|---|
|  | Parameter evaluation and derivation | <ul style="list-style-type: none"> <li>• Tabulation and review of the results of the field and laboratory work and evaluation according to BS EN 1997-2</li> <li>• Identification of any limitations in the data including defective, irrelevant, insufficient or inaccurate readings</li> <li>• Data on frost susceptibility of soils</li> <li>• Interpretation of the results taking account of the drilling and sampling methods used, the sample storage and transport and the specimen preparation</li> <li>• Consideration of any extreme (adverse or beneficial) results as to whether they are misleading or real and so require consideration in the design</li> <li>• Review of the derived values of all geotechnical parameters including consideration of any correlations used and their applicability</li> <li>• Histograms or other plots to illustrate the range of values of relevant parameters</li> <li>• Description of the evolution of and changes in the ground model from initial studies through the phases of investigation</li> <li>• Profiles or cross-sections showing the geometry of and differentiation between the various formations</li> <li>• Position of the ground water table and its seasonal fluctuations</li> <li>• Detailed description of all the formations including the range and distribution of physical properties including their strength and deformation characteristics</li> <li>• Comment on any irregularities such as pockets, cavities or discontinuities</li> <li>• Proposals for any necessary further field or laboratory work including justification through the specific questions that have to be answered</li> </ul> |
| Geotechnical Design Report (GDR)<br>[BS EN 1997-1:2004+A1:2013, 2.8] | Design report                       | <ul style="list-style-type: none"> <li>• Description of the site and surroundings</li> <li>• Description of the ground conditions</li> <li>• Presentation of site ground model</li> <li>• Proposed structure including actions</li> <li>• Characteristic and design values of soil and rock properties, including justification as appropriate</li> <li>• Standards applied</li> <li>• Suitability of the site with respect to the proposed construction and level of acceptable risks</li> <li>• Assumptions, data, methods of calculation and results of the verification of safety and serviceability</li> <li>• Geotechnical design calculations and drawings</li> <li>• Foundation design recommendations</li> </ul>   |
| Geotechnical Baseline Report (GBR)<br>[see 63.5]                     |                                     | <ul style="list-style-type: none"> <li>• Anticipated geology, soil and rock profiles</li> <li>• Anticipated groundwater conditions</li> <li>• All information relevant to establishment of baseline conditions</li> </ul>   |

Table 43 Summary of reporting requirements (5 of 5)

| Report  | Section  | Descriptive items to be included  |
|---|--|---|
| Geotechnical Design Report (GDR)<br>[BS EN 1997-1: 2004<br>+A1:2013, 2.8] | Supervision, monitoring and maintenance report | <ul style="list-style-type: none"> <li>Note of items to be checked during construction, requiring maintenance or monitoring</li> <li>The purpose of each set of observations or measurements</li> <li>The parts of the earthwork, ground and/or structure to be monitored</li> <li>The locations at which observations are to be made</li> <li>The frequency of observations or measurements</li> <li>Ways in which the observations or measurements are to be evaluated</li> <li>The range of values within which the results are to be expected</li> <li>Period of time for which monitoring is to continue after construction is complete</li> <li>The parties responsible for making observations or measurement, for interpreting the results and for maintaining the instruments</li> <li>Extract of all above items as appropriate to be handed to the owner/client</li> </ul> |

## 63 Reports

### 63.1 Contents common to all reports

#### 63.1.1 General

Interpretation is a continuous process, which should be begun in the preliminary stages of data collection with the construction of the initial ground model. Further interpretation of the ground conditions should be carried out as information from the site studies and ground investigation becomes available; this information should be used to detect and resolve anomalies as field and laboratory work progresses. At all stages the current version of the ground model should be used to allow the known information and unknowns to be identified, so that the questions that need to be addressed by the next phase of study or investigation can be formulated. The progressive resolution of these questions should be the aim of the investigation, although it is also normal for new questions to come forward as more becomes known about the site.

Engineering problems should also be evaluated along with the ground model as the data becomes available so that the geotechnical adviser can decide either what additional exploration and testing needs to be carried out or, where appropriate, what reductions in the original programme/scope are possible. These should be addressed in a geotechnical risk register.

The compiled GIR and GDR should include a number of parts, as outlined in Table 43.

*NOTE 1 Full details of the items to be covered are given in BS EN 1997-1 and BS EN 1997-2.*

A report should be prepared with the understanding that it is intended to eventually be the only record of what was found, as samples are likely to be destroyed or rendered unrepresentative.

*NOTE 2 Traditionally, the results are normally issued in the form of a limited number of bound or unbound copies of an official written report. An increasing number of reports and the data contained therein are presented as computer files; this may be as copies of the prepared report.*

Data should be maintained in parallel with the formal reporting recommended and this requirement should be included in specifications on all ground investigations. The requirements for data management are given in BS 8574.

*NOTE 3 A suitable format in which to provide the data is prepared by the AGS and is known as AGS format.<sup>16)</sup>*

The formal report should contain a description of the site and the procedures used, together with tables and diagrams giving the results. Copies of field and laboratory report forms and data sheets may be included in the formal report, but the originals should be preserved for a suitable period so that they are available for later reference. The practice of binding copies of these forms as a report volume for permanent reference has much to commend it; the client's requirements in this regard should be specified in the tender document.

### 63.1.2 The introduction

#### 63.1.2.1 General

The report should have an introduction stating for whom the work was done, the names of parties involved, the phase of the investigation, the geotechnical categories of the proposed structures, the dates of commissioning and the dates of various activities, and nature of the investigation, and its purpose, scope and general location.

#### 63.1.2.2 Description of site

The report should contain an unambiguous description of the geographical location of the site, so that the area covered can be readily located at a later date, when possibly most, if not all, of the existing landmarks might have disappeared. Where appropriate, this should include street names and the National Grid reference. The report should incorporate relevant findings of the field reconnaissance visit, desk study or notable features identified during the course of the works, including a reproduced section of the relevant Ordnance Survey map of the appropriate scale for clarity. Details of all relevant topographic features should be included.

An account should be given of the geology, geomorphology and hydrogeology of the site, and the sources from which the information was obtained should be stated.

*NOTE The amount of the data included depends on the complexity of the ground conditions in line with the nature of the work being planned and the amount of available data.*

### 63.2 Ground investigation and testing reports

#### 63.2.1 General

Report form templates should be provided in the field for recording information, and these should have prompts (questions, spaces or boxes) to ensure that all the required information is recorded at the time.

*NOTE 1 Templates may be paper forms or digital input screens. The latter have the advantage of not allowing the operator to move off an input screen unless all required data has been entered.*

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<sup>16)</sup> See <<http://www.ags.org.uk>> [last viewed 24 June 2015].

Field report forms should require the operator to record all the data necessary for the eventual interpretation of the borehole or field test in accordance with BS EN ISO 22475-1. Most of the information called for is needed to draw appropriate conclusions from the results of boring and field tests, and whatever layout is adopted, all such items should be recorded somewhere. The information should include flush type, core barrel type, bit used from/to, drill rig and over specific depths used.

*NOTE 2 Other data, such as that which might be needed for administrative purposes, have not been included.*

The reference number, location and depth of each investigation point, sample and test should be recorded. The location may take the form of a reference that can be related to the national or other appropriate grid, and marked on a drawing in such a way that it can be easily located at a later date if needed. The ground level at the test position should be measured and included when available; however, this is often not surveyed until after the test and so might not be available for inclusion in the field report.

*NOTE 3 Drilling foremen, technicians, engineers or geologists, as appropriate, fill in field report pro formas on paper or digitally. Certain of the more complex tests might have several pro formas, and are often referenced in more than one report; for instance, bearing or permeability tests in boreholes or trial pits. It is usual to require copies of the field reports to be made available soon after the tests, normally within a few days, or as specified, to demonstrate that the field data has been satisfactorily collected. These then form a complete contemporaneous record, although further processing of the data is usually necessary to derive a satisfactory presentation for the field report and the parameters for use in design. Inclusion of the relevant field records in the final report might be beneficial (see 63.1).*

Detailed information on the procedures and results should be reported in accordance with the standard under which the test is being carried out.

An account should be given of the methods of investigation and testing used and the standards followed. A summary of the scope of work should be provided and should detail the spacing and depths of the investigation points. It should include a description of all the equipment used, e.g. types of drilling rigs and tools, together with the relevant standards for testing, sampling or drilling to which the work has been carried out. A note should be made stating any limitations of the results and any difficulties experienced, e.g. ground disturbance or problems in recovering samples. Any testing for gases and other contaminants or observations of these in the boreholes and around the site should be reported. The dates when the exploratory work, ground gas monitoring and groundwater monitoring was done should also be recorded, together with a note about the weather conditions, if relevant.

The report should contain a drawing indicating the positions and ground levels of all pits, boreholes, field tests, etc. It should contain sufficient topographical information so that the exploratory hole positions and particularly monitoring installations can be located at a later date.

### 63.2.2 Exploratory hole logs

The exploratory hole log should be a record that is as objective a record as possible of the ground conditions at the investigation position before the ground was subjected to disturbance and loss by the drilling or excavation process. Some interpretation is necessary, if only to link sets of samples with a stratum description, but the degree of interpretation should be kept to a minimum unless this is necessary to provide information, in which case it should be clearly identified; the use of words such as “probably” or “possibly” is useful in this regard.

The exploratory hole log should be part of the factual data arising from the investigation. The final logs should be based on the visual examination and description of the exposures, the laboratory test results, the driller's daily report forms and what is known of the geology of the site. All the relevant data should be recorded.

*NOTE The logs can only be finalized when the appropriate field and laboratory work has been completed.*

Although there are no set rules on the method of presentation of the data, the logs should present all the data obtained in a readable form and give a picture in diagrams and words of the ground profile at the particular point where the hole was bored. The extent to which minor variations in soil and rock types should be recorded, together with any discrepancies, depends on the various purposes to which the information is to be put. Detail indents should be used on the log to clearly represent variability or complexity of the ground.

Most organizations carrying out ground investigations have standard forms for exploratory hole logs but it is seldom practical within these to make allowance for all data that might need to be recorded. A standard form can be made more flexible by leaving one or more columns without headings, so that these can be used for whatever particular data needs to be recorded. Full use should be made of any unused space on the last sheet of a log.

The information to be included on logs should be in accordance with BS EN ISO 22475-1.

### 63.2.3 Photography

#### COMMENTARY ON 63.2.3

*Further guidance on photography is given in Annex H.*

Rock and soil cores should be photographed when fresh and before any destructive logging is carried out. The photographs should be in colour, to a consistent format on any investigation, including job, borehole and depth references, together with a scale and standard colour chart, and be sensibly free from distortion. The photographs should be presented in the report. Core should preferably take up over half the area of a photograph.

*NOTE High resolution scanning or imagery is also available and can be a useful alternative to conventional photography, particularly when a large-scale viewable image of the core is required.*

Trial pit photographic records should include one or more faces and the spoil heap; all photographs should include a suitable and legible reference board. Artificial or flash lighting should normally be used.

### 63.2.4 In-situ tests

For in-situ tests, the information to be recorded should be as outlined in Section 7; more detailed requirements for many tests should be presented in accordance with the relevant parts of BS EN ISO 22476 or BS 1377.

*NOTE The contract specification might have special or additional requirements.*

### 63.2.5 Incidence and behaviour of groundwater

To obtain a clear understanding of the incidence and behaviour of groundwater, all data collected on the groundwater should be included and, where no groundwater was encountered, this too should be recorded. In addition, where it was not possible to carry out groundwater observations this should be noted; for instance, drilling with water flush or overwater, or boring at a rate much faster than water can make its way into the borehole.

Where the information derived from boreholes and excavations is concise, it should be included in the logs. When this is not possible, the data should be given elsewhere in the report, and the exploratory hole logs cross-referenced.

The position of the borehole casing and the borehole depth at the time of an observation should be stated.

All other data, including those from separate observation wells, should be given in a separate table. Where water has been added to or removed from the ground by the boring or drilling process, this should be recorded.

### 63.2.6 Location of investigation points

The report should contain tabulated coordinates and a plan showing the precise position of each investigation points so that it is possible to locate each position accurately even after demolitions and excavations have taken place. The locations of any abortive or cancelled investigation points might also usefully be reported.

Where extensive tracts of open featureless country are encountered, the position of the investigation point should be linked to a land survey. Ground levels related to a permanent datum should also be provided.

Coordinates and ground levels at investigation points should preferably be given to National Grid and Ordnance Datum. If a site or local grid is used, its origin and orientation should preferably be given.

### 63.2.7 Results of laboratory tests and visual description of samples

Guidance on the use of laboratory tests is provided in BS EN 1997-2. Where the test is covered by International Standards (e.g. BS EN ISO 17892 [all parts]) or British Standards (e.g. BS 1377 [all parts]), the reporting of the results should be in accordance with those standards; where a test is not so covered, all relevant details and data should be given. Where an extensive programme of testing has been undertaken, a summary should be provided in addition to the detailed results. Test results may also be presented in line with specific contract requirements. The precise test carried out should also be stated without ambiguity. Where the test is reasonably standard, for instance "consolidated, drained, triaxial, compression test on 100 mm diameter samples", the name alone suffices; but where the test is not standard, a full description should be given.

The visual descriptions (see Clause 60) may be shown on the same sheets as the results of the laboratory tests, or in a separate table.

If the tests indicate a soil different from that visually described, the description should not be discarded on that account but should be preserved as a record of the observer's opinion. The laboratory report forms and data sheets should be filed for possible future reference or separately bound and presented (see Section 9).

If the results of contamination testing, ground gas monitoring and groundwater monitoring are included, this should be done in accordance with the requirements of BS 10175, BS 8576 and BS EN ISO 22475-1, respectively.

*NOTE BS 10175 states that it is not sufficient to simply present contamination results in the form of a compilation of analytical certificates. The results are to be presented in the main text in such a way that they can be easily assimilated by the reader.*

### 63.2.8 Special reports

The results of any specialized study, e.g. detailed mineralogical analysis, should be identified in the main report text, with all results and details included as an annex. Where relevant, specialized reports should include details of the analysis undertaken, the standards adhered to and any relevant calibration certificates.

## 63.3 Ground Investigation Report (GIR)

### 63.3.1 Desk study and field reconnaissance

#### COMMENTARY ON 63.3.1

*The reports of the desk study and field reconnaissance may be stand-alone reports or may be incorporated into other sections of the Ground Investigation Report.*

The description of the site should include details of what was standing on the site at the time of the investigation and information on its past use, including the possibility or knowledge of any potentially contaminative land uses, contaminated ground or potentially hazardous ground gases (e.g. methane, carbon dioxide, volatile organic compounds [VOCs]). In addition, details of any past or present man-made underground features, such as basements, mineral or other extractive workings, placed material (Made Ground or engineered fill), access or drainage adits and other tunnels or services, should be included; this list is not exhaustive. Some comment should be made on the relative levels between the site and its surroundings, and whether there are conspicuous differences in level over the site itself. Where actual levels relevant to the Ordnance Datum are available, these should also be given. A full description of the site should include comment on features outside the site boundary. Potential resources for construction should be identified when required.

*NOTE 1 Guidance on desk studies and walk over surveys for investigation of potentially contaminated sites and sites where ground gas is of concern is given in BS 10175:2011+A1:2013, Clause 6 and BS 8576:2013, Clause 6.*

Field reconnaissance studies should be carried out with an open mind, not a prescriptive list, and so the person(s) carrying out the field reconnaissance, for instance, should be experienced in the terrain, the geology and the type of structure proposed.

*NOTE 2 A list of the matters to be included in a field reconnaissance is given in Table 43 and in BS EN 1997-1 and BS EN 1997-2.*

Information from previous ground investigations on or adjacent to the site should be emphasized. Where the information is scanty, it should either be given in total or a judicious selection should be made of those items most relevant to the proposed works or development. The soil and rock types identified and described in the report should be linked with the known geology of the site. Where published information and current usage provide conflicting geological nomenclature, this should be explained and the terminology selected for use in the report put into context.

### 63.3.2 Ground model and parameter derivation

#### 63.3.2.1 General

After the descriptive report, the results should be collated into a description of the stratigraphy, an assessment of the ground parameters relating to that stratigraphy and a description of the groundwater conditions.

*NOTE The level of interpretation input into this phase varies widely, depending on the contractual responsibilities of the various parties, so there can be no firm rules as to whether this phase is part of the descriptive report or the interpretation.*



The collector of the data and writer of the descriptive report can provide significant assistance to the designers and this detailed knowledge of the site should be utilized, so that the text of the report provides an account of the ground conditions with the required degree of interpretation at the agreed place.

The presentation on the ground conditions should be thorough and clear, as this provides the key point of information to the many different specialists who could be using the report on an individual site (e.g. grouting, groundwater control, piling or tunnelling). The subsequent assessment in the next section of the report might alter with change of end use, but this summary should not.

### 63.3.2.2 Ground types

The ground should be divided into an appropriate series of soil and rock types for which the engineering properties may be regarded as sensibly constant for the purpose in hand.

*NOTE This division is usually, though not always, closely related to the geological succession.*

A description of each ground type should be given and any anomalies that have been observed should be noted and commented on. In this context, it should be constantly borne in mind that all samples are, to a greater or lesser degree, disturbed and might not be truly representative of in-situ conditions. Similar caution should be taken in considering the results of in-situ tests.

### 63.3.2.3 Stratigraphy

An account should be given of the sequence of ground types as they occur in the various parts of the site. Wherever possible, the stratigraphy of the site should be tied into its topographical, geological and geomorphological features. Attention should be specifically drawn to any anomalies that could have a significant effect on the works being considered.

### 63.3.2.4 Borehole sections

#### COMMENTARY ON 63.3.2.4

*For the purpose of analysis, it is often necessary to make basic assumptions about the ground profile at the site. These assumptions are best conveyed in a report by a series of cross-sections illustrating the ground profile, simplified as required, with groundwater levels shown. The presentation of a borehole section in a descriptive report would usually not include joining up the boreholes by stratum boundaries; the same section in the interpretative report would normally require joining up, using all the available information and suitably qualified in any areas of doubt. Accurate and integrated interpretation of geological maps, boreholes and other data is a prerequisite to a thorough understanding of the ground.*

Borehole sections in a ground conditions report should be interpreted, but this should be clarified at an early stage. Borehole sections should preferably be plotted to a natural scale and, if it is necessary to exaggerate the vertical scale, this should be clearly indicated. Where the ground information is either very variable or too sparse to enable cross-sections to be prepared, individual borehole logs plotted diagrammatically should be used as an acceptable alternative.

*NOTE Where it is particularly important to prepare cross-sections, sparse and variable information can sometimes be supplemented between boreholes by means of information from soundings and geophysical investigations. It can be helpful to indicate relevant soil parameters on sections, e.g. results of standard penetration tests, triaxial tests or earthworks relationship tests.*

### 63.3.2.5 Ground parameters

There is no universally accepted method of selecting these parameters, but the following approach should be adopted to try and arrive at reliable values:

- a) compare laboratory and in-situ test results with ground descriptions;
- b) cross-check, where possible, laboratory and in-situ results in the same ground;
- c) consider bias in the measurements available resulting from difficulties in sampling or testing materials from all parts of the site or the succession, such as at the boundary between soil and rock;
- d) account for ground variability and collect individually acceptable results for each formation and decide representative values appropriate to the number of results;
- e) compare the representative values with experience and published data for similar geological formations;
- f) consider and explain apparently anomalous or extreme results especially if values are discounted when providing a designated mean and/or characteristic value;
- g) consider parameters required in the context of the development proposals; and
- h) highlight any limitations to the data or analyses.

### 63.3.2.6 Groundwater

The report should describe regional groundwater conditions and the presence or otherwise of perched, artesian or downward draining conditions. Comment should be made on any anomalies and the possibility of the rise or fall of groundwater with the tide, season or other long-term variation.

It should be taken into account that the design proposals might require the results to be interpreted in different ways to ensure adequate design of different elements of the works or different forms of groundwater control.

Further monitoring needed prior to, during and following construction should be highlighted in the report.

### 63.3.2.7 Chemical conditions

Comment should be made on chemical conditions in the ground and groundwater, not only with regard to potential attack on buried parts of the structure, but also with regard to possible effects in construction and service life, whether these be due to natural causes or to man's activities. Any conditions that could affect health and safety during construction or in subsequent use should be mentioned. Where further specialist investigation or analysis could be required, recommendations should be highlighted within the report.

## 63.4 Geotechnical Design Report (GDR)

### COMMENTARY ON 63.4

*The following list, which is by no means exhaustive, indicates the topics on which advice and recommendations are often required. The level of comment required here varies but an underlying need is the identification of ground-based risks and hazards. Given the availability of a wide and ever-changing range of proprietary systems, all of which interact with the ground in subtly different ways, it is important that the report writer does not overstate their level of knowledge.*

*A robust ground model which is then interrogated and evolved through the whole investigation process is critical to the success of the investigation process. By identifying the uncertainties in the knowledge about the ground, sensible decisions can be made as to the need for further investigation. This further investigation might include additional sub-surface investigation, examination of exposures within the construction or by monitoring of the structure during and after its completion. Monitoring can be part of an observational approach to the design, when the performance is checked against design assumptions.*

#### 63.4.1 General

The GDR should provide all parties with the information needed to assess the suitability of various options and the design of the works. It should include the following information.

- a) Spread foundations: level, either in terms of a depth or to a stated stratum; safe or allowable bearing capacity; estimated total and differential settlements; possible alternative types of foundation; possible ground treatment; effects of nearby trees.
- b) Piles: types suited to the ground and groundwater profile and environment; estimated safe working loads, or data from which they can be assessed; estimated settlements of structures; ease of installation such as for driven piles; need for pile tests.
- c) Retaining walls: lateral pressures or data from which they can be derived; wall friction; bearing capacity; groundwater conditions.
- d) Basements: comment on the possibility of flotation; estimate the rise of the basement floor during construction and groundwater levels.
- e) Ground anchorages: bearing stratum and estimated safe loads, or data from which they can be calculated.
- f) Chemical attack: most commonly takes the form of recommendations for protecting buried concrete against attack from sulfate-bearing soils and groundwater. The results are usually evaluated by reference to *BRE Special Digest 1* [N1]. Also to be considered is the possibility of corrosion of steel in saline waters or in the presence of sulfate-reducing bacteria. The effect of acidic or highly alkaline soils might also need to be considered. The presence of contaminated soils, especially those containing high concentrations of organic chemicals, should be taken into account for their effects on all building materials, including effects on services. These factors should also be evaluated with regard to health and safety during construction and in subsequent use of the structure.
- g) Pavement design: assessment of appropriate design parameters or California Bearing Ratios; type and thickness of pavement; possibility of using soil stabilization for forming pavement bases or sub-bases; recommendations, where appropriate, for sub-grade drainage; comment on susceptibility of soil at formation level to frost heave.
- h) Slope stability: recommendations on temporary and permanent slopes for excavations, including, where appropriate, drainage measures. Comment should be made, where relevant, on the possibility of weathering of rock faces and the available methods of dealing with this hazard. Recommendations for the monitoring of unstable slopes might also be required.
- i) Mining subsidence: description of the workings; voids and stability; possible recommendations for methods of filling known cavities near the surface; the design of structures to withstand movements without damage or measures to limit the damage and simplify repairs.

- j) Natural cavities: description of the cavities; voids and stability; possible recommendations for methods of filling known cavities near the surface; the design of structures to withstand movements without damage or measures to limit the damage and simplify repairs.
- k) Tunnels and underground works: a description of the ground through which the tunnel is to be driven; possible covering of the following points: methods and sequence of excavation; whether excavation is likely to be stable without support; suggested methods of lining in unstable excavations; potential use of rock bolting; likelihood of encountering groundwater and recommendations for dealing with it; special features for pressure tunnels; risk of encountering ground or water contamination; possibility of natural or man-made gases.
- l) Safety of neighbouring structures: an assessment of the likely amount of movement caused by adjacent excavations and groundwater lowering, compressed air working, grouting and ground freezing or other geotechnical processes. The possibility of movement due to increased loading on adjacent ground might also need to be considered.
- m) Monitoring of movements: comment on the necessity for measuring the amount of movement taking place in structure and slopes, together with recommendations for the method to be used; recommendations for taking photographs before the commencement of works (see Annex H).
- n) Embankments: comment on stability of embankment foundations; assessment of amount and rate of settlement and the possibility of hastening it by such means as vertical drains; recommendations for side slopes; choice of constructional materials and methods; parameters for control of earthworks.
- o) Drainage: comment on possible drainage methods during construction for works above and below ground; general permanent land drainage schemes for extensive areas.
- p) Planning requirements: enable the discharge of planning conditions.

Where calculations have been made, they should be included as an annex, or a clear indication of the methods used should be given. The calculation methodology might form a significant part of the GDR.

#### 63.4.2 Construction expedients

Comments and recommendations are often needed on the points listed below and safety aspects should be included where appropriate.

- a) Open excavations: method and sequence of excavation; what support is needed; how to avoid boiling and bottom heave; estimated upward movement of floor of excavation. Comment on relative merits of sheet piling and diaphragm or bored pile walls where appropriate.
- b) Underground excavations: method and sequence of excavation and the need for temporary roof and side support; dealing with gases.
- c) Groundwater: likely flow, head and quantity and how to deal with it.
- d) Driven piles, bored piles and ground anchors: methods of driving or construction suited to the ground profile, environment and neighbouring buildings.
- e) Grouting: types of grouts likely to be successful in the ground and recommended method of injection.
- f) Mechanical improvement of soil below ground level. Comment on the suitability of techniques for the consolidation of loose soils.

- g) Contamination: known or suspected contaminants and gases in soil, groundwater and any cavities. Comment on health and safety aspects both during and after construction, see BS 10175.
- h) Monitoring during construction works, e.g. stability of deep excavations, vibrations and movement near other structures.
- i) The need for sustainability: this can include selecting appropriate materials from appropriate sources as well as in the methods to be used for construction. Geotechnical structures can also be used to access shallow geothermal energy sources for building heating and cooling. The design of such structures needs to be considered at an early phase of the investigation process and appropriate testing carried out in the investigation.

### 63.4.3 Sources of materials for construction

The following sources of materials for construction should be taken into account.

- a) Fill: possibility of using excavated material for this purpose with an assessment of the proportions of usable material; methods and standards of compaction; possible off-site sources of fill; bulking factor.
- b) Aggregates: in areas where no commercial sources are available, the possibilities of winning and processing materials available locally.
- c) Groundwater as a construction material.

*NOTE* In many parts of the world, and even parts of the UK, sources of water for use in construction cannot be assumed to be available in the quantities required, and this requires consultation with the water supply authorities through the use of piped, surface or ground water sources.

### 63.4.4 Parameter characterization

#### COMMENTARY ON 63.4.4

*Methods of analyzing ground data and applying them to the solution of engineering problems are not covered in this British Standard. For guidance on this, see BS 5493, BS 6031, BS 7361-1, BS 8002, BS 8004 and CP 2012-1.*

The report should include comment on the compatibility of existing information and new information, and in particular draw attention to anomalies and proposed further investigation to address such matters.

The report should also present the current status of the ground conditions as incorporated in the ground model; by this stage the model ought to be mature and should provide a comprehensive identification of ground-based hazards and risks to the design and construction. Any uncertainties that remain should be discussed, and any plans for their resolution presented; it might also be the case that further investigation to resolve anomalies has been decided against for cost benefit reasons; these should also be discussed.

A clear statement should be made about the data on which the analysis and recommendations are based, particularly any limitations and variability. Any concerns/issues should be recorded in the geotechnical risk register and suggestions for resolution presented.

*NOTE* The information comes under two separate headings, as follows.

- a) The information related to the project and usually supplied by the designer. For example, for buildings and other structures this should include full details on the loading, split into dead and live; column spacing, where appropriate; and depth and extent of basements and details of neighbouring structures. For earthworks, heights of embankments and the materials of which they are to be made, together with the depths of cuttings, are all relevant to the interpretation.
- b) Ground parameters, selected from the summary of ground conditions report by the engineer making the analysis and preparing the recommendations.

### 63.4.5 Supervision, monitoring and maintenance report

#### COMMENTARY ON 63.4.5

*It is important to note that investigation is not complete once the design of the geotechnical structure is completed. Investigation is an on-going process through the construction with observations being made to confirm assumptions made in the design and to look for any deviations from the expected ground or groundwater conditions. The design of the structure might also require measurements to be made of settlements or other movements.*

The frequency and locations of checks should be identified in the GDR and communicated to those involved with construction on site. In addition, it should be made clear who is to make these checks and there should be a procedure for review and action in place, if necessary.

In accordance with BS EN 1997 an extract from the GDR containing the supervision, monitoring and maintenance requirements for the completed structure should be provided to the owner/client.

### 63.5 Geotechnical Baseline Report (GBR)

The GBR should set out the anticipated geology, soil and rock profiles and groundwater conditions. The GBR should be agreed between all parties to the contract before the construction works commence and it should be agreed which party is liable for any deviation from the identified conditions. The GBR should then be used during construction to measure the conditions actually encountered and to operate the changed physical conditions clause in the construction contract.

*NOTE* The intention of the GBR is to place an equitable, safe and economic balance for the risk for the ground between the parties. The GBR may include factual elements of the GIR.

### 63.6 Failures

Where a ground investigation has been undertaken in an attempt to identify the cause of failures, the following points should be taken into account.

- a) Foundations: the nature and dimensions of the foundations, identification of the type and cause of failure and, where appropriate, an estimate of the amount of settlement or heave that has already occurred, together with an assessment of how much more is likely to occur and its probable effect on the structure; cause of excessive vibrations of machine foundations; recommendations for remedial measures.
- b) Landslides or slope instability: classification of the type of movement and location of the failure surfaces; recommendations for immediate stabilizing expedients and long-term measures; recommendations for monitoring.
- c) Embankments: identification of whether the seat of failure lies within the embankment itself or the underlying strata, the probable cause and suggested method of repair and strengthening.

- d) Retaining walls: comment on cause of failure or excessive deflection; forecast of future behaviour of wall and recommendations where appropriate for strengthening it; recommendations for monitoring.
- e) Pavements: determination of whether the failure is within the pavement itself or the sub-grade and recommendations for repairs or strengthening or both; recommendations for monitoring.
- f) Differential ground movement: provide summary of details for main types, including natural and anthropogenic such as karst, formation, dissolution of soluble ground, mining; summarize effects on development.
- g) Mining or natural cavity related failures: determine likelihood of further movement; recommendations for repairs or strengthening or both and any monitoring.

### 63.7 Geotechnical Feedback Report (GFR)

A Geotechnical Feedback Report (GFR) should be prepared where required.

*NOTE* The contents of this report might include the topics detailed in BS 8002 and BS 8004 and in the contract specification.

## Section 11: Review during and after construction

### 64 General

#### COMMENTARY ON CLAUSE 64

*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. It is also the case that for many investigations the exact locations of the proposed structures have not been determined and so the ground conditions relevant to the individual structures is not always known.*

The ground exposed during construction and the behaviour of structures during and after construction should be monitored to verify that the predictions made during design remain valid.

### 65 Purpose of review

Review during construction should be carried out 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. For maximum benefit, this review should be directed by the geotechnical adviser (see Clause 6).

Where additional and/or different information is revealed during construction, the design and construction should be reviewed and the design or the construction procedures might need to be amended as a result of the review.

*NOTE In certain cases it might 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 designer and the contractor.*

The information collected during construction should be used 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 can be reassessed;
- d) check assumptions about ground conditions related to construction methods, which might include groundwater;
- e) check the suitability of instrument installations;
- f) enable the best use to be made of excavated materials;
- g) reassess the choice of construction plant and equipment; and
- h) provide agreed information about ground and groundwater conditions in the event of dispute.

The results of the investigation which is carried out after construction should be used to verify that the structure is behaving in accordance with the predictions made by the designer.



## 66 Information required

### 66.1 Soil and rock

Accurate engineering descriptions of all strata encountered below ground level should be made in accordance with Section 6. The soil and rock 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.

*NOTE It might be advantageous to arrange for the site to be inspected by the organization that carried out the ground investigations, particularly if conditions appear to differ significantly from those described in the ground investigation.*

### 66.2 Groundwater

Accurate information about the groundwater should be obtained during construction and 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. The effect of groundwater lowering should also be recorded in observation holes to determine the extent of the cone of depression and changes to ground level for sensitive structures as required.

## 67 Monitoring

### COMMENTARY ON CLAUSE 67

*Instruments and subsequent observations used during and after construction can include measurement of pore pressure, seepage, earth pressure, settlement or heave and lateral movements.*

Monitoring by means of inspection or instrumentation should be carried out wherever appropriate; this might require the installation of appropriate instruments additional to those that were installed as part of the pre-construction investigations. If existing instruments are used, their correct functioning should be verified and this might require fresh calibrations. Readings of the instrumentation can 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.

*NOTE Monitoring might be necessary to check that construction works can proceed safely or on large or critical structures such as earth dams, embankments on soft ground, large buildings with underground construction, deep excavations or tunnels.*

Monitoring should be carried out in accordance with BS EN 1997-1:2004+A1:2013, 2.7 and the following should be identified:

- who makes observations and where, and who reads which instruments and when;
- the party that receives the observations;
- the review to be carried out, checking against the acceptable limits of behaviour; and
- the contingency actions to be adopted if the monitoring reveals unacceptable performance.

These requirements should be set out in the monitoring and maintenance report that is included within the safety file and passed to the client.

## **68 Reporting**

The findings of all construction and post-construction investigations should be incorporated into or appended to the GIR and GDR as appropriate.

**Annex A  
(informative)****National safety legislation and guidance***COMMENTARY ON ANNEX A*

*This annex describes the regulatory regimes and associated guidance available in July 2015. It is provided for information only. Readers cannot rely on this annex to provide a complete account of the current legal position or the relevant guidance and need to make sure that they have up-to-date information.*

**A.1 Health and Safety at Work etc. Act 1974**

The Health and Safety at Work etc. Act 1974 [130] 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, Approved Codes of Practice, Codes of Practice, Guidance Notes and other published information that define the requirement for safety on sites where investigation and construction work is being carried out.

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 at Work Regulations 1999 [149], employers 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.

Certain risks are attached to working on investigation sites and these risks are associated with particular circumstances or hazards. The significant hazards are required to be assessed and provision made for safe working through developed Risk Assessments in the site-specific Construction Phase Plan. The Association of Geotechnical and Geoenvironmental Specialists (AGS) have developed industry-specific safety guidance for activities which includes significant hazards such as trial pitting, underground and overhead services, work over and adjacent to water, work in confined spaces and work on contaminated land.

**A.2 Management of Health and Safety at Work Regulations 1999**

The Management of Health and Safety at Work Regulations 1999 [149] outline the essential content of a safety management system and the principles of risk assessment and prevention that are to be followed in all workplaces. It also outlines the requirements for health surveillance and where this is to be implemented.

**A.3 Construction (Design and Management) Regulations 2015 (CDM)**

All intrusive ground investigations, geotechnical advice and design and other associated activities fall within the scope of the Construction (Design and Management) Regulations 2015 [7], also referred to as CDM. The CDM Regulations cover notification of the project, impose duties on all clients, contractors and employees, create additional duty holders of Principal Contractor and Principal Designer, require that a site-specific Construction Phase 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. All designers are required to consider the hierarchy of risk reduction in their works and communicate with other designers and contractors on the project to reduce risk.

The project is notifiable by the client if the construction phase lasts longer than 30 working days and has more than 20 workers working simultaneously at any point in the project or exceeds 500 person days.

Part 4 and Schedule 2 duties of the Construction (Design and Management) Regulations 2015 [7], which outline how hazards are to be managed and the extent to which welfare is required to be provided, apply to all construction sites. These apply to the employers, employees and self-employed carrying out investigation and construction work.

#### **A.4 Work at Height Regulations 2005**

The Work at Height Regulations 2005 [150] are the primary legislation relating to managing the risk of work at height which for geotechnical work includes working on scaffolds, working at the edge of a trial pit and working adjacent to or upon rock/soil slopes. A risk assessment is required to be completed by the employer of anyone (SI engineer/visitors included) who might be involved in working at height. Employers are required to follow the hierarchy of control measures, which moves from elimination of the requirement to work at height through to removing the possibility of falling from height (i.e. permanent barrier) or reducing the height worked at to provision of protection devices (i.e. safety nets/crash mats) and PPE.

#### **A.5 Provision and Use of Work Equipment Regulations 1998 (PUWER)**

The Provision and Use of Work Equipment Regulations 1998 [151], also known as PUWER, relate to any work equipment including site plant such as drilling rigs, excavators, etc., laboratory equipment and office equipment. The equipment is required to be fit for purpose, safe to use and operated by competent and trained personnel. Visual and/or physical inspections are required, especially for equipment that is robustly used. Maintenance, servicing and rig guarding are all part of the requirements of PUWER.

#### **A.6 Lifting Operations and Lifting Equipment Regulations 1998 (LOLER)**

The Lifting Operations and Lifting Equipment Regulations 1998 [152], also known as LOLER, relate to any piece of plant that lifts and includes cable tool rigs, lifting elements of rotary rigs such as ropes, excavators when used for lifting, telehandlers and jacking devices. Lifting equipment includes swivels, shackles, ropes, chains, slings and any loops used for lifting (i.e. top of SPT hammer). These are required to be thoroughly inspected and certified, uniquely identified and marked with a safe working load (SWL). All lifting work requires a lifting plan, although in cases where the work is regularly repeated (such as the lifting of drilling tooling using the rig) this can be covered with general risk assessments and method statements.

#### **A.7 Manual Handling Operations Regulations 1992**

Incorrect manual handling accounts for over a third of all workplace injuries. Heavy manual labour, awkward postures, manual materials handling (i.e. handling, moving and lifting bulk samples and core) and previous or existing injury are all risk factors in developing musculoskeletal disorders (MSDs). Attention is drawn to the Manual Handling Operations Regulations 1992 [153] which gives guidance on manual handling.

*NOTE For more information, see the manual handling information on the HSE website.*<sup>17)</sup>

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<sup>17)</sup> See <<http://www.hse.gov.uk/contact/faqs/manualhandling.htm>> [last viewed 24 June 2015].

### A.8 Control of Noise at Work Regulations 2005

Noise at work can cause hearing damage that is permanent and disabling. Noise at work can interfere with communications and make warnings harder to hear. It can also reduce people's awareness of their surroundings, i.e. standing next to a percussion rig or diesel engines during excessive work, sampling and especially SPT tests. Attention is drawn to the Control of Noise at Work Regulations 2005 [154] which cover this. For outside work, the driller and team are required to have ear protection, and although supervisors can reduce impact by distance, ear protection is still important.

### A.9 Control of Vibration at Work Regulations 2005

Hand-arm vibration (HAV) can arise from the use of hand-held power tools and can cause significant ill health (painful and disabling disorders of the blood vessels, nerves and joints). Hand-held tools include using jack hammers, hand-held window samplers and coring rigs. The Control of Vibration at Work Regulations 2005 [155] place specific duties on employers to identify and control the risk of employees' exposure to hand-arm vibration. Data is available for the majority of such equipment and includes exposure action values which indicate the daily level when control measures are required and exposure limit values which indicate maximum daily levels.

### A.10 Control of Substances Hazardous to Health Regulations (COSHH)

The Control of Substances Hazardous to Health Regulations 2002 (COSHH) [156] cover the protection of people at work and members of the public who might be exposed to health risks and the environment arising from hazardous substances.

The COSHH Regulations only apply to substances which can cause harm to human health. Safety data sheets are provided for chemicals and dangerous substances to be used by the employer as a basis to carry out a COSHH (risk) assessment. Control measures are required to take account of how the substance is used, handled and stored to avoid entry into or damage to the human body. Employers are also required to monitor the health of employees exposed to substances during their work.

For mixed chemicals, the manufacturers' safety data sheet (SDS) is unlikely to provide guidance on the effects and expert advice might be required.

Bacterial hazards such as leptospirosis, anthrax, etc. do not have safety data sheets, but are still considered to fall under COSHH.

Any contaminated land investigation could involve COSHH substances.

### A.11 Confined Spaces Regulations 1997

The Confined Spaces Regulations 1997 [157] defines a "confined space" as any space of an enclosed nature where there is a risk of death or serious injury from hazardous substances or dangerous conditions (e.g. lack of oxygen or increase in carbon dioxide concentrations). Other than obvious location-specific spaces (e.g. manholes, sewers), trial pits and shafts (especially those which are required to be entered) can easily become confined spaces, either because of ground gas or because ground can collapse or groundwater can flood.

## A.12 Control of Asbestos Regulations 2012

The presence of asbestos fibres or asbestos containing materials (e.g. fragments of asbestos cement sheeting) in the ground can present risks to health and requires particular care in the selection of appropriate sampling techniques and design of sampling procedures. Care is required in ensuring that any asbestos containing samples are identified before the sample goes to the chemical or geotechnical laboratory.

Breathing in air containing asbestos fibres can lead to asbestos-related diseases, mainly cancers of the lungs and chest lining. Asbestos is only a risk to health if asbestos fibres are released into the air and breathed in. The Control of Asbestos Regulations 2012 [158] help duty holders (building owners and developers), people carrying out asbestos surveys and those with specific responsibilities for managing the risks from asbestos to control the risk and discharge their duties.

*NOTE* See AGS Site Investigation Asbestos Risk Assessment – For the Protection of Site Investigation [159].

## A.13 New Roads and Street Works Act (NRSWA) 1991

The New Roads and Street Works Act (NRSWA) 1991 [160], together with the Street Works (Qualification of Supervisors and Operatives) Regulations 2009 [161], is investigation work that disrupts the highway (roads and pavements). This work requires all operatives who open up the highway to be NRSWA trained and that each road opening project has a NRSWA trained supervisor. In addition, traffic management is required to be set up, maintained and dismantled by NRSWA trained operatives.

Working on or adjacent to roads is hazardous; this can include road traffic accidents which can occur on site and in travel to and from site. This latter hazard is increased when travel covers long distances.

## A.14 Avoiding danger from underground services

HSE guidance, HSG47 [3], provides a framework to reduce the risk of encountering, exposing and potentially damaging underground services. The guidance outlines a three-step approach – plan (including obtaining and consulting maps and plans), locate/identify and then excavate/penetrate the ground. It also discusses safe digging techniques, i.e. vacuum excavation, utility surveys and use of cable locating devices, i.e. Cable Avoidance Tools (CAT) and Genny and Ground Penetrating Radar (GPR).

PAS 128 provides additional non-mandatory guidance on best practice.

## A.15 Personal Protective Equipment (PPE) at Work Regulations 1992

PPE is defined in the Personal Protective Equipment (PPE) Regulations 1992 [162] as “all equipment (including clothing affording protection against the weather) intended to be worn or held by a person at work and which protects them against one or more risks to their health or safety”, e.g. safety helmets, gloves, eye protection, ear defenders, high-visibility clothing, safety footwear and safety harnesses.

## A.16 Respiratory protective equipment (RPE)

HSE guidance, HSG53 [163] provides essential guidance for the correct selection and use of respiratory protective equipment (RPE) in the workplace, which assists companies in complying with their duties under COSHH and the PPE Regulations.

**A.17 Regulatory Reform (Fire Safety) Order 2005**

The Regulatory Reform (Fire Safety) Order 2005 [164] requires all workplaces to be subject to fire risk assessments, including construction sites.

**A.18 Dangerous Substances and Explosive Atmospheres Regulations 2002**

The intention of the Dangerous Substances and Explosive Atmospheres Regulations 2002 [165] is to reduce the risk of a fatality or serious injury resulting from a “dangerous substance” igniting and potentially exploding. Such atmospheres can be caused during the liberation of ground gases in coal workings, landfills or similar.

**Annex B  
(informative)****General information for a desk study****B.1 General land survey**

Information on the following is needed to carry out a general land survey (see also Annex C):

- a) location of site on published maps and charts;
- b) aerial imagery of suitable spatial scale, all dated and geo-located where appropriate;
- c) site boundaries, outlines of structures and building lines;
- d) ground contours and natural drainage features;
- e) obstructions to sight lines and ship/aircraft movement, for example transmission lines;
- f) indication of obstructions below ground;
- g) indication of the possible presence of Unexploded Ordnance;
- h) routes of services/utilities or infrastructure including underground or overground pipes or cables;
- i) record of differences and omissions in relation to published maps;
- j) position of survey stations and benchmarks (the latter with reduced levels); and
- k) meteorological information.

**B.2 Permitted uses and restrictions**

The following information on permitted uses and restrictions is needed:

- a) planning and statutory restrictions applying to the particular areas under the Town and Country Planning Acts administered by appropriate planning authorities;
- b) local authority regulations on planning restrictions, listed buildings and building bye-laws;
- c) right of light, support and way, including any easements, land covenants and structural precautions;
- d) tunnels; mine workings, abandoned, active and proposed, mineral rights and ownership, and authorizations/permits to work (e.g. Network Rail and the Coal Authority);
- e) ancient monuments and burial grounds;

- f) previous potentially contaminative uses of the site and adjacent areas (see 17.9, BS 10175 and BS 8576);
- g) any restrictions imposed by environmental and ecological considerations, e.g. sites of special scientific interest;
- h) working near watercourses: any permitting required by the Environment Agency;
- i) duty of care requirements to local residents, e.g. noise and vibration; and
- j) working hours, e.g. night time working due to traffic management restrictions.

### **B.3 Approaches and access (including temporary access for construction purposes)**

Information on the following is needed:

- a) road (check ownership and potential need for traffic management);
- b) railway (check for closure);
- c) by water;
- d) by air;
- e) for coastal investigations: tide levels and timings; and
- f) land use (for example arable or pasture) and vegetation (for example, grassed playing field or woodland).

### **B.4 Ground conditions**

The following information on ground conditions is needed:

- a) geological maps including soil maps, hydrogeological maps, aquifer designation maps (see C.2.1);
- b) geological memoirs;
- c) previous land use from, for example, Ordnance Survey maps;
- d) flooding, erosion, landslide, mining and subsidence history;
- e) data held by central and local authorities;
- f) previous and current construction and investigation records of the site and adjacent sites (as applicable);
- g) seismicity;
- h) lake, reservoir, tide levels and timings; and
- i) information related to voids.

### **B.5 Sources of material for construction**

Information on the following sources of material for construction is needed:

- a) natural materials;
- b) groundwater;
- c) tips and waste materials; and
- d) imported materials.



## B.6 Drainage and sewage

The following information on drainage and sewage is needed:

- a) names of sewage, land drainage and other authorities concerned and their bye-laws;
- b) locations and levels of existing systems (including field drains and ditches), showing sizes of pipes, and whether foul, storm water or combined;
- c) existing flow quantities and capacity for additional flow;
- d) liability to surcharging;
- e) charges for drainage and disposal facilities;
- f) neighbouring streams or public sewers capable of taking sewage or trade effluents provided they are purified to the required standard;
- g) disposal of solid waste; and
- h) flood risk to proposed works.

## B.7 Water supply including groundwater

The following information on water supply is needed:

- a) names of authorities concerned and their bye-laws;
- b) locations, sizes and depths of mains;
- c) pressure characteristics of mains;
- d) water analysis;
- e) availability of water for additional requirements;
- f) storage requirements;
- g) water source for fire-fighting;
- h) charges for connections and water;
- i) possible additional sources of water including groundwater; and
- j) water rights and responsibilities under the Water Resources Act 1991 [166].

## B.8 Electricity supply

The following information on electricity supply is needed:

- a) names of supply authorities concerned and regulations;
- b) locations of existing electricity supply infrastructure;
- c) the voltage, phases and frequency;
- d) capacity to supply additional requirements;
- e) transformer requirements; and
- f) charges for installation and usage.

**B.9 Gas supply**

The following information on gas supply is needed:

- a) names of supply authorities concerned and regulations;
- b) locations, sizes and depths of mains;
- c) type of gas, thermal quality and pressure;
- d) capacity to supply additional requirements; and
- e) charges for installation and gas usage.

**B.10 Telecommunications**

The following information on telecommunications is needed:

- a) addresses of local offices;
- b) location of existing lines;
- c) telephone agency requirements; and
- d) charges for installation and operation.

**B.11 Heating**

The following information on heating is needed:

- a) availability of fuel supplies;
- b) planning restrictions (smokeless zone; Clean Air Act 1993 [167] administered by local authorities); and
- c) district heating.

**B.12 Information related to potential contamination**

The following information is needed to assess the potential for contamination:

- a) history of the site, including details of owners, occupiers and users, and any incidents or accidents relating to dispersal of contaminants;
- b) processes used, including their locations;
- c) nature and volume of raw materials, products, waste residues;
- d) waste disposal activities and methods of handling waste;
- e) layout of the site above and below ground at each stage of development, including roadways, storage areas, hard-cover areas, and the presence of any extant structures and services;
- f) presence of any waste disposal tips, abandoned pits, mines and quarries; and
- g) presence of nearby sources of contamination from which contaminants could migrate via air and/or groundwater onto the site under consideration.

**Annex C  
(informative)****Sources of information****C.1 Ordnance Survey**

As Great Britain's national mapping authority, Ordnance Survey produces a wide range of products documenting the physical and social geography of Great Britain, including historical maps. For current information, see the Ordnance Survey website.<sup>18)</sup>

**C.2 Geological survey, soil survey maps and reports****C.2.1 Geological maps and reports****C.2.1.1 General**

The British Geological Survey (BGS) is the national repository for geoscience data in the UK. It is the custodian of an extensive collection of digital data, maps, records and materials relating to the geology of the UK, its continental shelf and many countries overseas. Digital indexes to the collections have been established and selective geographical searches of data availability are carried out using a GIS-based information retrieval system. The BGS operates a central enquiry desk at its Keyworth office. Enquiries dealing with particular localities can be processed online through the GeoIndex or GeoReports Service or can be submitted by email or post, accompanied by a marked-up copy of a map or by eight-figure national grid references defining the area in question.

Local libraries can also provide a source of geological information for the locality. The Geological Society at Burlington House, London has an extensive library for the use of its members and bona fide researchers.

**C.2.1.2 Maps**

The British Geological Survey produces geological and thematic maps at scales between 1:10 000 and 1:1 million scale covering both onshore and offshore areas. The 1:10 000 scale series of geological maps are available for large areas of the country, particularly urban areas. Geological maps at this scale are published digitally (DiGMapGB-10) with a print on demand option for those requiring a paper copy. The geology presented in these maps is structured in five themes.

- a) Bedrock geology is the main mass of rocks forming the Earth and is present everywhere, whether exposed at the surface in outcrops or concealed beneath artificial ground, mass movement deposits, superficial deposits or water.
- b) Artificial ground where the ground surface has been significantly modified by human activity.
- c) Linear features related primarily to the bedrock theme, being either an intrinsic part of it (e.g. a mineral vein) or affecting it (e.g. a fault).
- d) Mass movement deposits are masses of rock, earth or debris that have moved downslope under gravity and are generally known as landslides.
- e) Superficial deposits are the youngest geological deposits formed during the most recent period of geological time, the Quaternary, which extends back about 2.6 million years from the present.

<sup>18)</sup> See <[www.ordnancesurvey.co.uk](http://www.ordnancesurvey.co.uk)> [last viewed 24 June 2015].

1:50 000 scale geological maps provide onshore national coverage and are available digitally (DiGMapGB-50) as an online view service on the BGS website, BGS mobile website and as apps for various devices; partial national coverage of litho-printed maps at this scale or a site-specific map report containing digital map extracts as part of the GeoReport service. The geology presented in these maps has the same five themes as the 1:10 000 scale map series.

Onshore digital geological maps are available at a scale of 1:625 000; the themes are bedrock geology and superficial (with mass movement, dykes and linear (fault) features). These are available for free viewing on (and download from) the BGS website. Litho-printed 1:625 000 scale geological maps are also available for purchase.

Offshore digital geological maps are available at a scale of 1:250 000 as DigRock250 and DigSBS250 providing details of the solid geology and seabed sediments. Litho-printed versions are available at the same scale.

The British Geological Survey produces a range of 1:50 000 scale digital thematic maps of Great Britain (see Table C.1) including:

- a) the DiGMapGB-plus Engineering Properties dataset (including strength and excavatability);
- b) the Superficial Deposit thickness digital model showing the modelled depth to the bedrock surface;
- c) the GeoSure dataset provides information about potential ground movements or subsidence including:
  - 1) collapsible deposits;
  - 2) compressible ground;
  - 3) landslides;
  - 4) running sand;
  - 5) soils with shrink swell properties; and
  - 6) soluble rocks.
- d) the mining hazard (not including coal) dataset provides essential information to developers building in areas of former shallow mining for resources other than coal;
- e) the radon potential dataset which is the definitive map for radon affected areas in Great Britain;
- f) geological indicators of flood potential such as floodplains and coastal plains and, therefore, those areas at greater risk of flooding;
- g) susceptibility to groundwater flooding;
- h) the infiltration SuDS (Sustainable urban Drainage Systems) map provides invaluable information to those involved in designing sustainable urban drainage systems as part of a development.

A range of applied geology maps covering new town and development areas, and engineering geology maps associated with special local or regional studies are available. These maps normally accompany open-file reports but can also be purchased separately. The BGS has also published hydrogeological maps of the whole of the UK and more detailed maps of major aquifer units, and geophysical maps of gravity and aeromagnetic anomalies covering the British Isles and its continental shelf.

Table C.1 BGS maps

| Map series                          | Scale and type  | Coverage                        |
|-------------------------------------|---|---------------------------------|
| DiGMapGB-10                         | 1:10 000 scale digital onshore geological maps  | Partial coverage                |
| DiGMapGB-50                         | 1:50 000 scale digital onshore geological maps  | National coverage               |
| DiGMapGB-250                        | 1:250 000 scale digital onshore geological maps   | National coverage               |
| DiGMapGB-625                        | 1:625 000 scale digital onshore geological maps   | National coverage               |
| DiGMapGB-Plus                       | 1:50 000 scale digital value-added onshore geological maps including Engineering Properties   | National coverage               |
| DigRock250                          | 1:250 000 scale digital offshore geological maps  | UK and adjacent European waters |
| DigSBS250                           | 1:250 000 scale digital offshore sea-bed sediment maps  | UK and adjacent European waters |
| Thematic geological maps and models | 1:50 000 scale maps and models covering a range of parameters such as Engineering Properties, Thickness of Superficial Deposits, Groundwater flooding, etc. | –                               |
| Printed geological maps             | Available in a range of scales between 1:50 000 and 1:625 000   | –                               |
| 1:10 000 scale geological maps      | 1:10 000 scale geological map, partial coverage, print on demand or copy on demand service  | –                               |

#### C.2.1.3 Models, virtual borehole and virtual cross-section viewers

The BGS has developed a series of new products and web-based tools to assist in the understanding of geology in three or more dimensions. These products include geological modelling systems that produce three- and four-dimensional geological models, some of which are available for viewing on the BGS website and others that can be licensed.

Tools have been developed and are published on the BGS website that allow a user to “drill” virtual boreholes or draw virtual cross-sections through a geological model. This service is only available for selected areas at present but is intended to become more widespread over time.

*NOTE The user needs to understand the scale and uncertainties of these products.*

#### C.2.1.4 Reports

The BGS has produced a number of published and unpublished report series describing aspects of geology. These include:

- British Regional Geology Guides: a series of 20 handbooks describing the geology of individual regions of the United Kingdom;
- Offshore regional report: a series of reports describing the offshore geology of the United Kingdom which has been published to complement the British Regional Geology Guides;
- Memoirs: the 1:50 000 and 1:63 360 geological map series were formally accompanied by a series of explanatory sheet memoirs. They include coalfield and economic memoirs for selected areas of the country. The memoir series has been published over many years and the geological interpretations in the older editions might have been changed. Copies of out of print memoirs can be obtained from the BGS’s Library at Keyworth, Nottingham;
- Reports: a series of reports, variously known as Technical Reports, Open File Reports, Commissioned Reports, etc., contain a wealth of detailed geological and related information. A number of these were created in parallel to the mapping of 1:10 000 scale geological map sheets and are often identified as

“Geological notes and local details”. The BGS has also published a series of engineering geology studies of bedrock formations such as the Gault Formation, Lias Group, etc. Some of these publications are freely available through the online NERC (Natural Environment Research Council) Open Research Archive (NORA).<sup>19)</sup>

- GeoReports: a GeoReport is site specific, as requested by the customer. It provides cost-effective access to unique sources of published and unpublished geological data, combined with expert advice from BGS scientists who know about the local area. The reports are either automatically generated from the British Geological Survey databases or are bespoke. Bespoke reports describe the various layers of man-made and natural geology expected to be underlying a site; it also includes geological map extracts and a list of the available data sources. They can be customized with additional modules such as Engineering Geological, Hydrogeology and Drilling Considerations.

#### **C.2.1.5 Borehole records**

The BGS has scanned over a million borehole records and made them available through a free Borehole Record Viewer. This offers direct, online access to the onshore borehole collection held by the National Geoscience Data Centre comprising boreholes drilled for a range of purposes including:

- ground investigation, for example for highways;
- water abstraction;
- ground source heat pumps;
- mineral exploration;
- mining;
- oil and gas exploration; and
- geological research.

#### **C.2.1.6 Hydrogeological information**

A BGS hydrogeological database, called WellMaster, holds details of many thousands of water boreholes and wells. The database includes information on geology, well construction, water levels and yields; water quality has also been digitized for the majority of water boreholes, if the information is available. All this information is available via the BGS website.

#### **C.2.1.7 Library services**

The BGS library at Keyworth offers a range of literature search services, commercial desk-top study facilities and other related services. Library facilities are also available at the BGS Edinburgh office.

#### **C.2.1.8 National Geoscience Data Centre and National Geological Repository**

The most comprehensive collection of information about subsurfaces is at the National Geoscience Data Centre. Part of the BGS, the National Geoscience Data Centre and the National Geological Repository comprises data gathered or generated by the BGS or its precursors, in addition to data provided by numerous external organizations.

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<sup>19)</sup> See <<https://nora.nerc.ac.uk/>> [last viewed 24 June 2015].

The National Geoscience Data Centre manages digital data storage whilst the National Geological Repository holds over 500 km of drill core and 4.5 million core samples. Together they hold tens of millions of items of data and documents, including about 90 000 ground investigations.

The large majority of this collection is available for public consultation.

#### C.2.1.9 Enquiries service

The British Geological Survey runs a central enquires desk.

|                 |   |
|-----------------|---|
| Postal address: | Enquiries<br>British Geological Survey<br>Keyworth<br>Nottingham<br>NG12 5GG  |
| Email:          | enquiries@bgs.ac.uk   |
| Telephone:      | +44(0)115 936 3143  |
| Website         | <a href="http://www.bgs.ac.uk">http://www.bgs.ac.uk</a> [last viewed 24 June 2015]  |
| BGS Offices     | <a href="http://www.bgs.ac.uk/contacts/offices.html">http://www.bgs.ac.uk/contacts/offices.html</a><br>[last viewed 24 June 2015] |

### C.3 Soil and hydrogeological maps

#### C.3.1 Soil maps

Soils maps depict the distribution of soil types in the landscape and incorporate much information that is potentially useful for ground investigations.

Soils are defined by the Soil Survey of Great Britain (SSGB) as the thin upper layer, nominally 1.2 m of material at the Earth's surface and take into account particle-size distribution, chemical characteristics, drainage and parent material. Certain soil types are defined in other ways, for example, peats are defined by their botanical composition and state of humification and can vary in depth from 0.5 m to over 10 m. The occurrence of compressible materials, shrinkable clays, shallow depth to rock, unconsolidated sands and degrees of natural soil wetness and drainage can all be assessed from soil maps. Special maps showing peat distribution, groundwater vulnerability to pollution and the risk of erosion by water are also available.

Publications lists and soils information for England and Wales is held by the National Soil Resources Institute<sup>20)</sup> within the Department of Environmental Science and Technology at Cranfield University. The Macaulay Land Use Research Institute<sup>21)</sup> in Aberdeen (part of the James Hutton Institute) holds the information for Scotland. The Agri-Food and Biosciences Institute (AFBI)<sup>22)</sup>, a non-departmental public body within the Department of Agriculture and Rural Development in Belfast, holds data for Northern Ireland.

<sup>20)</sup> National Soils Resources Institute, Cranfield University, Cranfield, Bedfordshire, MK43 0AL. Tel: +44(0)1234 750111, Web: <[www.cranfield.ac.uk](http://www.cranfield.ac.uk)> [last viewed 24 June 2015].

<sup>21)</sup> Macaulay Land Use Research Institute, Craigiebuckler, Aberdeen, AB15 8QH. Tel: +44(0)844 928 5428, Web: <[www.macaulay.ac.uk](http://www.macaulay.ac.uk)> [last viewed 24 June 2015].

<sup>22)</sup> AFBI, Newforge Lane, Belfast, BT9 5PX. Tel: +44(0)2890 255636, Web: <[www.afbini.gov.uk](http://www.afbini.gov.uk)> [last viewed 24 June 2015].

### C.3.2 Hydrogeological maps

Hydrogeological maps are published at scales of 1:63 360, 1:50 000 and 1:25 000 for large areas of Great Britain and there is complete cover for England, Wales and Scotland at the 1:625 000 scale, and at 1:250 000 scale for Northern Ireland. Groundwater vulnerability maps of Scotland at a scale of 1:625 000 and Northern Ireland at a scale of 1:250 000 are published by the BGS. A series of maps covering England and Wales at 1:100 000 has been produced for the Environment Agency and is available from the Stationery Office.<sup>23)</sup> The Environment Agency has also produced aquifer designation maps.

Scans of published hydrogeological maps can be viewed at:  
<http://www.bgs.ac.uk/data/maps/home.html> [last viewed 24 June 2015].

Information is also available on the Environment Agency website:  
<http://www.ea.gov.uk> [last viewed 24 June 2015].

In addition there is much unpublished archive data and surveys which can be consulted by arrangement with the appropriate institutes.

## C.4 Marine information

### C.4.1 Charts

The UK Hydrographic Office of the Ministry of Defence publishes charts for nearly all the navigable tidal waterways of the world to various scales. The charts show high and low water lines and the levels of the sea and river beds with reference to a datum that is defined on the chart, together with certain other tidal information.

### C.4.2 Tide tables

Admiralty Tide Tables are published annually (in hard copy form) in four volumes:

- Vol. 1: European waters (including the Mediterranean Sea);
- Vol. 2: The Atlantic Ocean;
- Vol. 3: The Indian Ocean; and
- Vol. 4: The Pacific Ocean and adjacent seas.

Each of these consists of three parts:

- Part I gives predictions of the times and heights of high and low water at standard ports;
- Part II gives data for prediction at secondary ports; and
- Part III gives the harmonic constants for all standard and most secondary ports.

### C.4.3 Other publications

The Hydrographic Office also publishes books of sailing directions, general information on tides and other navigational publications, which, together with the charts, are listed in the Catalogue of Admiralty Charts and other Hydrographic Publications (which also includes a list of agents), published annually.

Further information on Admiralty charts and hydrographic publications can be obtained direct from the Hydrographer of the Navy.<sup>24)</sup>

<sup>23)</sup> See <[www.tso.co.uk](http://www.tso.co.uk)> [last viewed 24 June 2015].

<sup>24)</sup> UK Hydrographic Office, Admiralty Way, Taunton, Somerset, TA1 2DN. Tel: +44 (0)1823 337900, Web: <[www.ukho.gov.uk](http://www.ukho.gov.uk)> [last viewed 24 June 2015].



## C.5 Meteorological information

### C.5.1 Reports

The Meteorological Office collects and publishes meteorological information in the United Kingdom in various forms:

- a) Monthly: The monthly weather report summarizes weather observations for about 600 stations in the United Kingdom. Principal data include air temperature, rainfall and sunshine. There are summaries of autographic records of wind from about 130 stations, and frequency tables of the occurrence of air temperatures between certain limits for about 20 stations. Additionally, an annual summary has frequency tables of sunshine, rainfall and wind speed. The monthly weather report is normally published about 8 months in arrears to allow time for all the data to be collected and quality controlled.
- b) Annually: Monthly and annual rainfall totals for about 6 000 stations, together with amounts and dates of maximum daily falls, are published in Rainfall 19xx ("xx" signifies the particular year of interest). Monthly, annual and seasonal rainfall as a percentage of annual average, frequency of distributions of daily rainfall, amounts and spells of rainfall, and rainfall excess or deficiency are included for selected stations. Heavy falls of rain are also listed. Rainfall 19xx is normally published two to three years after the end of the year to which it relates.
- c) Other information: Where up-to-date information is not available, local statutory bodies, including the Environmental Regulators (i.e. the Environment Agency, the Scottish Environmental Protection Agency, Environment Wales) can be useful sources of data.

### C.5.2 Statistics

Averages and extremes for various elements are published from time to time. Tables of temperature, relative humidity and precipitation for the world are published by the Meteorological Office, giving climatic tables for some 1 800 stations throughout the world. Data consist of means and extremes for varying periods depending on the station.

All enquiries concerning the availability and prices of historical weather data can be addressed to the Meteorological Office.<sup>25)</sup>

## C.6 Hydrological information

Surface water flow and run-off data is collected by the environment agencies, water companies, private water undertakings and occasionally by local authorities or academic researchers. Since 1985, both surface water flow data and groundwater level data have been published jointly by the Centre for Ecology and Hydrology (CEH) and the British Geological Survey (BGS) through the National Hydrological Monitoring Programme (see <http://www.ceh.ac.uk/data/nrfa/nhmp/nhmp.html> for further information [last viewed 24 June 2015]).

Evapotranspiration and soil moisture information is issued weekly by the Meteorological Office as part of the MORECS (Meteorological Office Rainfall and Evaporation Calculation System) service, which includes data on potential evapotranspiration over Great Britain. All enquiries concerning MORECS should be addressed to the Meteorological Office.

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<sup>25)</sup> The Meteorological Office, FitzRoy Road, Exeter, Devon, EX1 3PB. Tel: +44 (0) 1392 885680, Web: <[www.metoffice.gov.uk](http://www.metoffice.gov.uk)> [last viewed 24 June 2015].

## c.7 Aerial photographs and satellite imagery

There are many collections of aerial photographs for the United Kingdom extending back over several decades. These are not centrally archived and there is no complete index available. In order to establish availability for a particular area of the country, it might be necessary to contact several sources.

The key national archives of aerial photographs in the UK are:

- a) for England – English Heritage Archive;<sup>26)</sup>
- b) for Wales – Central Register of Air Photography for Wales;<sup>27)</sup>
- c) for Scotland – Royal Commission on the Ancient and Historic Monuments of Scotland (RCAHMS);<sup>28)</sup>
- d) for Northern Ireland – Land and Property Services, Department of Finance and Personnel Northern Ireland.<sup>29)</sup>

Dedicated acquisition of remote sensing data from aerial platforms is principally available via commercial organizations such as:

- 1) The Environment Agency Geomatics Group;<sup>30)</sup>
- 2) GetMapping;<sup>31)</sup>
- 3) BlueSky.<sup>32)</sup>

Each of these organizations can acquire a range of remote sensing data including LIDAR, thermal imaging, and multispectral and hyper-spectral imagery, and derivative products such as elevation models.

Remote sensing imagery (airborne and satellite) is also available via platforms such as NASA's Whirlwind. These online systems are versatile tools for viewing recent and past images online, and basic functionality is provided to digitize linework.

While vertical photographs from conventional aircraft were once the dominant source of imagery, recent very high resolution (VHR) satellite imagery, e.g. from SPOT, Pleiades, RapidEye, IKONOS, etc., is proving a viable alternative. Photographs and imagery derived from remotely piloted air systems (RPAS), sometimes also referred to as unmanned aerial vehicles (UAVs), are also becoming a standard tool in surveying with many suppliers in the UK.

<sup>26)</sup> English Heritage Archive, The Engine House, Fire Fly Avenue, Swindon, SN2 2EH. Tel: +44 (0)1793 414700, Web: <[www.english-heritage.org.uk/professional/archives-and-collections](http://www.english-heritage.org.uk/professional/archives-and-collections)> [last viewed 24 June 2015].

<sup>27)</sup> Central Register of Air Photography for Wales, Air Photographs Unit, Welsh Government, Crown Offices, Cathays Park, Cardiff, CF10 3NQ. Tel: +44 (0)2920 823819, Web: <[www.nationalarchives.gov.uk](http://www.nationalarchives.gov.uk)> [last viewed 24 June 2015].

<sup>28)</sup> Royal Commission on the Ancient and Historic Monuments of Scotland (RCAHMS), John Sinclair House, 16 Bernard Terrace, Edinburgh, EH8 9NX. Tel:+44 (0)131 662 1456, Web: <[www.rchams.gov.uk](http://www.rchams.gov.uk)> [last viewed 24 June 2015].

<sup>29)</sup> Land and Property Services, Department of Finance and Personnel Northern Ireland, Lincoln Building, 27-45 Great Victoria Street, Malone Lower, Belfast, BT2 7SL. Tel: +44 (0)300 200 7804, Web: <[www.dfpni.gov.uk/lps](http://www.dfpni.gov.uk/lps)> [last viewed 24 June 2015].

<sup>30)</sup> See <<https://www.geomatics-group.co.uk/geocms>> [last viewed 24 June 2015].

<sup>31)</sup> See <<http://www1.getmapping.com>> [last viewed 24 June 2015].

<sup>32)</sup> See <<http://www.bluesky-world.com>> [last viewed 24 June 2015].

## c.8 Seismological information

Computer listings and maps of earthquakes occurring in the United Kingdom and elsewhere can be obtained from the Global Seismology Group of the BGS, based in Edinburgh.<sup>33)</sup> The information, which is accumulated from the World Network, and the seismographs and seismographic arrays in the United Kingdom, includes time of occurrence, epicentral distance, focal depth and magnitude. The listing includes historical references from a wide range of sources from both the United Kingdom and elsewhere. On request, the data can be converted to a quantitative assessment of the seismic hazard at a site, including the probability of a particular ground acceleration being exceeded (per year).

## c.9 Information related to voids

Several publications are available giving guidance on sources of information for mine-related desk studies. The principal sources of information specific to voids are listed below:

- BGS mining portal;
- Natural Cavities database held by Peter Brett Associates and the BGS<sup>34)</sup>;
- UK Coal Authority databases<sup>35)</sup> including the Catalogue of Abandoned Coal Mines, Coal Mining Referral Area Maps;
- Review of Mining Instability in Great Britain prepared by Ove Arup on behalf of the Department of the Environment;
- the Cheshire Brine Subsidence Compensation Board database (regarding solution mining of salt in Cheshire);
- catalogue of Plans of Abandoned Mines for Minerals other than Coal and Oil Shale, held by Local Authorities (formerly held by The Health and Safety Executive);
- local enquiries to mining and quarry firms, mining consultants, local authorities, or even individuals can often produce information about abandoned mines and quarries that is unobtainable elsewhere; and
- plans and records of refuse tips associated with abandoned mines and quarries maintained under the Mines and Quarries (Tips) Act 1969 [168].

## c.10 Other sources of information

Other sources of information include:

- a) the maps of the Second Land Utilization Survey of Britain;<sup>36)</sup>
- b) records of mines and mineral deposits (see C.9);
- c) maps published by a number of individuals before the establishment of the Ordnance Survey. Copies of these can often be found in public libraries and local museums;
- d) UXO bomb damage maps; and
- e) Goad insurance maps.

<sup>33)</sup> British Geological Survey, Global Seismology Group, Murchison House, West Mains Road, Edinburgh GH9 3LA.

<sup>34)</sup> See <<http://www.bgs.ac.uk/caves/NKD.html>> [last viewed 24 June 2015].

<sup>35)</sup> See <[www.gov.uk/government/organisations/the-coal-authority](http://www.gov.uk/government/organisations/the-coal-authority)> [last viewed 24 June 2015].

<sup>36)</sup> The published maps, an index map and the Land Use Survey Handbook can be obtained from the Director, Kings College, Strand, London, WC2; or from Edward Stanford Ltd, 12-14 Long Acre, London WC2.

The *Transport Research Laboratory Report 192* [10] is another useful source of information.

Annex D  
(informative)

## Detailed information for design and construction

### D.1 General

For most projects, the design and planning of construction requires a detailed examination of the site and its surroundings (a CIRIA project to develop guidance covering all the key stages in the planning and set-up of a construction site is underway at the time of publication). Such requirements might necessitate a detailed land survey (see **D.2**), or an investigation of liability to flooding. The investigation of ground conditions is dealt with in other sections in this British Standard, e.g. Section 3. Other requirements might entail studies of subjects such as unexploded ordnance (see **D.5**), hydrography (see **D.6**); climate (see **D.7**); hydrology (see **D.8**); sources of materials (see **D.9**); and disposal of waste materials (see **D.10**).

### D.2 Detailed land survey

The following information can be gathered when carrying out a detailed land survey.

- a) Detailed survey of site and its boundaries (particularly marked changes in ground levels), including levels referring to Ordnance datum, means of access, public and other services, and natural drainage network (see Annex C).
- b) Present and previous use of site and particulars of existing structures and obstructions, and whether they have to be maintained or demolished.
- c) Adjoining property and differences in ground levels with particulars of any adjacent structures including heights, floor levels, type of foundation and other details, and whether support is needed for these adjacent structures.
- d) Location and depth, where known, of any underground obstructions, and features such as cavities and mine workings and tunnels with a full description (see Annex F).
- e) Location with co-ordinates of triangulation and traverse stations (Ordnance Survey and site) positions and levels of Ordnance Survey and site bench marks, true north points and date of survey.
- f) Establish site bench marks and record their nature, location and description.
- g) Establish whether easements are required.
- h) Location, height and type of trees especially where site is underlain by fine soils and shallow footings are likely to be used.

### D.3 Aerial photography

See Clause 14 and C.7.

### D.4 Ground conditions

Ground conditions, including the possibility of contaminated ground, are dealt with elsewhere in this British Standard, e.g. Section 2, and also in BS 10175 and BS 8576.

### D.5 Unexploded ordnance

For areas where there is known to be a risk of encountering unexploded ordnance, impact assessments of the study areas can be made following the guidance given in CIRIA C681 [21].

Geophysical methods can be used to search for potential UXOs (see Clause 27). From the surface a grid form survey can be used:

- Magnetometer – This locates ferrous features to around 4 m – 5 m depth. Responses typical of UXOs can be differentiated in size and depth to some degree, though false anomalies can be expected. The value of this survey is dependent upon the localized environment being clear of ferrous debris, services, etc.
- Electromagnetic (EM) – This detects both non-ferrous and ferrous metallic objects. It is typically less sensitive to background noise than the Magnetometer, and is slightly more limited in depth penetration than the Magnetometer but provides additional information on the nature of the materials.
- GPR can be used for location of specific features, but is not typically recommended for most sites.

The exact nature of the targets to be located with these techniques can only be determined by excavation. As such, these techniques are used to minimize risk of unforeseen obstructions.

When drilling, techniques such as combined magnetometer CPT cone can be used to minimize risk of encountering UXOs below the depth of resolution of surface techniques.

## D.6 Hydrography and hydraulic models

Structures in, adjoining, or near waterways require information on some or all of the following.

- a) Requirements of statutory bodies controlling waterways, such as port authorities, environment agencies, water companies, planning authorities and fisheries.
- b) Topographical and marine survey data to supplement, where appropriate, Ordnance Survey maps and Admiralty charts and publications (see Annex C).
- c) Detailed information about rivers, size and nature of catchment areas, tidal limits, flood levels and their relations to Ordnance datum.
- d) Observations on tidal levels (referred to Ordnance datum) and the rate of tidal fluctuations, velocity and directions of currents, variations in depth, and wave data.
- e) Information on scour and siltation, movement of foreshore material by drift; stability conditions of beaches, dunes, cliffs, breakwaters and training works.
- f) Location and details of existing river and marine structures, wrecks and other obstructions above and below the water line. Include effect of obstructions and floating debris, etc., on permanent and temporary works, including clearances.
- g) Observations on the condition of existing structures, such as attack by marine growth and borers, corrosion of metal work, disintegration of concrete and attrition by floating debris or bed movements.

## D.7 Climate

Information on the following can be obtained from publications of the Meteorological Office (see C.5) and, where necessary, supplemented from local sources:

- a) annual rainfall and seasonal distribution;
- b) severity and incidence of storms;

- c) direction and strength of prevailing and strongest winds with their seasonal distributions;
- d) local air flow characteristics;
- e) liability to fogs;
- f) range of temperature, seasonal and daily; and
- g) humidity conditions.

## D.8 Hydrology

Some sites might be liable to flooding. Information on sources of published data is given in Annex C. It can sometimes be advantageous to set up data collection, initially on-site, specifically orientated to the investigation, and then again later, at the construction stage. Parameters such as rainfall, wind, river and tide levels, maximum and minimum temperature and ground water levels can be measured, preferably on a regular daily or weekly basis. Where appropriate, the continuation of data collection might be possible with the liaison of the controlling statutory bodies. Even short-term data collection can provide a better understanding of the site conditions in the context of all previously recorded data.

Data is also available giving local and regional precipitation and flow data.

## D.9 Sources of materials for construction

The following are all sources of materials for construction:

- a) topsoil;
- b) fill for earthworks and reclamation;
- c) road base and surfacing materials;
- d) concrete aggregates;
- e) stone for building, rip rap or pitching; and
- f) water.

## D.10 Disposal of waste and surplus materials

The following information is needed to dispose of waste and surplus materials:

- a) location and capacity of spoil tips, including those for surplus dredged materials;
- b) requirements to safeguard nearby structures from ground movements and slips;
- c) liquid waste and standards of pre-treatment required;
- d) solid waste;
- e) access to spoil tips;
- f) transport requirements; and
- g) effect on environment, particularly in respect of any contaminated waste materials.

Annex E  
(informative)  
E.1

## Notes on field reconnaissance

### General

Field reconnaissance is carried out once the factual information for the site and its environs has been compiled and preliminary proposals for any ground investigation prepared. Additional information on the geology and hydrogeology, potential construction and access constraints for ground investigation might be revealed by the field reconnaissance. The following are some key points to consider when undertaking the field reconnaissance.

- a) Traverse the whole area, preferably on foot.
- b) Set out the proposed location of work on plans, where appropriate.
- c) Observe and record differences and omissions on plans and maps; for example, boundaries, buildings, roads and transmission lines.
- d) Inspect and record details of existing structures.
- e) Observe and record obstructions; for example, transmission lines, ancient monuments, trees subject to preservation orders, manhole covers, gas and water pipes, electricity cables, sewers.
- f) Check access, including the probable effects of investigation plant and construction traffic and heavy construction loads on existing roads, bridges and services.
- g) Check and note water levels, direction and rate of flow in rivers, streams and canals, and also flood levels and tidal and other fluctuations, where relevant.
- h) Observe and record adjacent property and the likelihood of its being affected by the proposed works and any activities that might have led to contamination of the site under investigation.
- i) Observe and record mine or quarry workings, old workings, old structures, and any other features that might be relevant.
- j) Observe and record any obvious immediate hazards to public health and safety (including to trespassers) or the environment.
- k) Observe and record any areas of discoloured soil, polluted water, distressed vegetation or significant odours.
- l) Observe and record any evidence of gas production or underground combustion.
- m) Tree types and locations if site underlain by fine soils.

### E.2 Ground information

The following steps can be followed when gathering ground information.

- a) Observe the ground morphology and associated features to provide information on the geomorphology of the site and surrounding area. Study and record surface features, on-site and nearby, preferably in conjunction with Ordnance Survey mapping, geological maps and remote sensed images, and note the following:
  - 1) type and variability of surface conditions;
  - 2) comparison of surface lands and topography with previous map records to check for presence of fill, erosion or cuttings;
  - 3) steps in surface, which might indicate geological faults or shatter zones. In mining areas, steps in the ground are probably the result of mining subsidence. Other evidence of mining subsidence should be looked for:

- compression and tensile damage in brickwork, buildings and roads; structures out of plumb; interference with drainage patterns;
- 4) mounds and hummocks in more or less flat country which frequently indicate former glacial conditions; for example, till and glacial gravel. Similarly, hollows and depressions, locally water-filled, could also indicate former glacial conditions;
  - 5) broken and terraced ground on hill slopes, which might be due to landslips; small steps and inclined tree trunks can be evidence of creep;
  - 6) crater-like holes in chalk or limestone country, which usually indicate swallow holes filled with soft material; and
  - 7) low-lying flat areas in hill country, which might be sites of former lakes and could indicate the presence of soft silty soils and peat.
- b) Assess and record details of ground conditions in any exposures in quarries, cuttings and escarpments, on-site and nearby.
  - c) Assess and record, where relevant, ground water level or levels (often different from water course and lake levels), positions of wells and springs, and occurrence of artesian flow.
  - d) Study and note the nature of vegetation in relation to the soil type and to the wetness of the soil (all indications require confirmation by further investigation). Unusual green patches, rushes (e.g. *Juncus sp.*), willow trees (*Salix sp.*), alder (*Alnus glutinosa*) and black poplar (*Populus nigra*) usually indicate wet ground conditions.
  - e) Study embankments, buildings and other structures in the vicinity having a settlement history, in particular, looking for cracks in walls, subsiding floors, and other structural defects.

### E.3 Field reconnaissance for ground investigation

The following steps can be followed when carrying out field reconnaissance. Referenced photographs can form part of the subsequent record.

- a) Inspect and record location and conditions of access to working sites.
- b) Observe and record obstructions, such as overhead or underground pipes and cables, boundary fences and trenches, trees and other vegetation clearance requirements.
- c) Locate and record areas for depot, offices, sample storage, field laboratories.
- d) Ascertain and record ownership of working sites, where appropriate.
- e) Consider liability to pay compensation for damage caused.
- f) Locate a suitable water supply where applicable and record location and estimated flow.
- g) Locate a suitable means of disposing of solids and liquid arising from the investigation.
- h) Record particulars of lodgings and local labour, as appropriate.
- i) Record particulars of local telephone including mobile phone reception, employment, transport and other services.
- j) Note the surface conditions at each exploratory hole and the particular reinstatement requirements (e.g. breaking out of pavement and replacement).
- k) Record details of post investigation access to instrumentation and any requirements to protect the instrument (e.g. fencing).



Annex F  
(informative)

## Ground investigations and development in ground potentially containing voids

### F.1 General

Where ground has the potential to contain voids, and there is insufficient or inappropriate consideration of them, the presence of such voids can present geotechnical, environmental and/or health and safety hazards to proposed development, which adversely impact the existing use of land or prevent the safe occupation or enjoyment of land.

Such geohazards include:

- formation of voids at the ground surface;
- ground subsidence;
- toxic and asphyxiating gases;
- combustible materials;
- rising water levels;
- mines and natural cavities acting as pollution pathways; and
- contamination.

As well as the risks that such geohazards could present to a new development or the existing use of the land, a cavity of any sort might have achieved some level of metastability, which can easily be disturbed, for example, by changes in stress brought about by ground investigation or construction.

In the United Kingdom, responsibilities are placed on planning authorities and developers via the planning legislation to ensure that the future development of land is safe, sustainable and appropriate.

*NOTE Attention is drawn to the existence of local planning authorities and planning legislation.*

The responsibility to mitigate potential hazards associated with land potentially affected by mining, quarrying and natural cavities remains with the developers of the land.

### F.2 Classification of voids

To enable organizations, such as consulting engineers and contractors, to design appropriate ground investigations to assess the potential for voids to exist beneath development land, and then to enable the significance of any voids to be assessed, it is fundamental that consideration is given at the earliest stages of investigation to the possible sources of such voids.

A classification of voids, based on their mode of formation, can aid the understanding of the associated hazards and identifying suitable investigation strategies. The classification presented in this annex follows that proposed in Donnelly and Culshaw, 2012 [169].

Voids can be grouped as those formed from either natural processes or those formed from the actions of man, i.e. anthropogenic activities. The principal types of voids are presented in Figure F.1 and further information and references are provided in Table F.1.

Figure F.1 Principal types of void

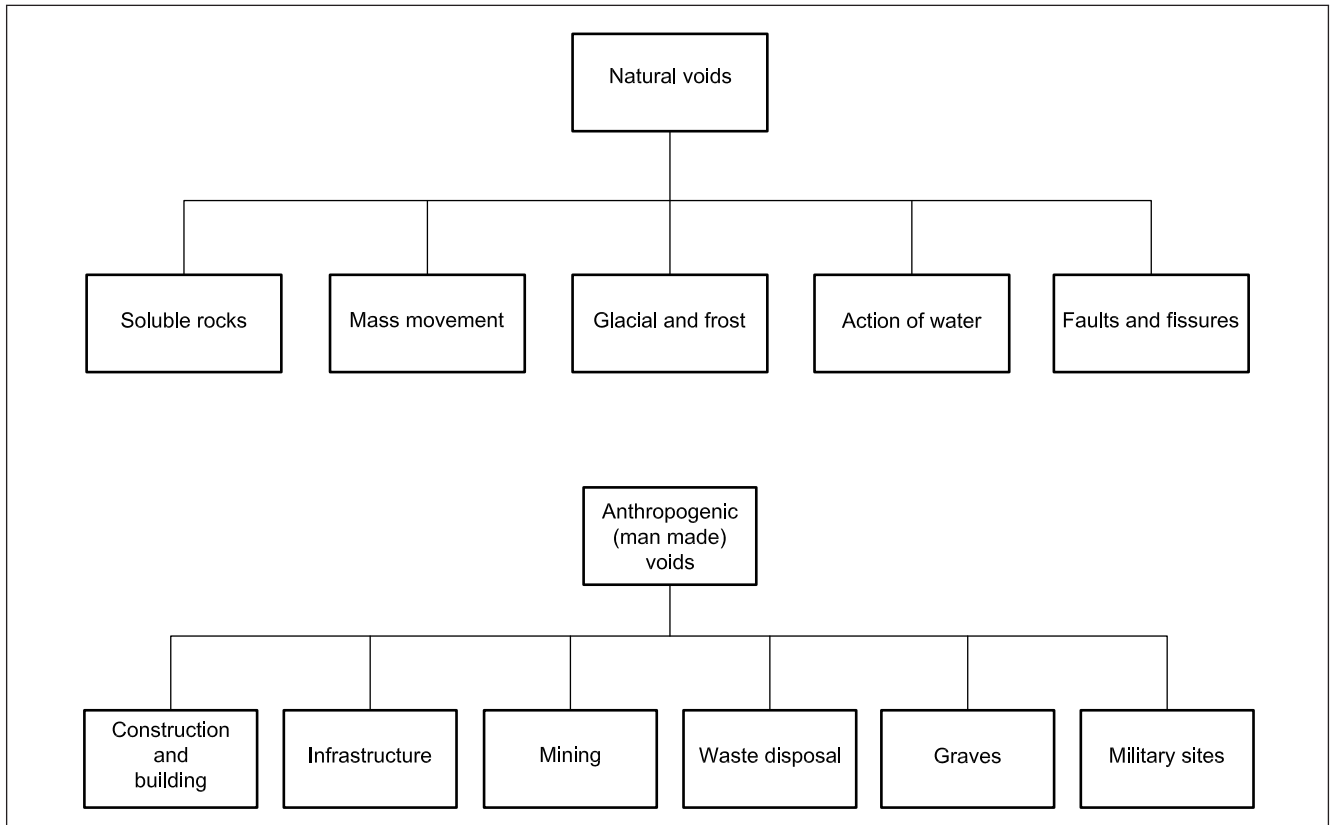


Table F.1 Principal types of void (1 of 2)

| Void type                    | Subdivisions                          | Characteristics  |
|------------------------------|---------------------------------------|--|
| <b>Natural</b>               |                                       |  |
| Caves in more soluble rocks  | Caves in limestone                    | Voids in limestone/dolomitic limestone.  |
|                              | Caves in gypsum/anhydrite             | Voids in gypsum/anhydrite.   |
|                              | Breccia pipes                         | Choked near vertical pipes formed by the collapse of voids below.  |
| Sinkholes (dolines)          | Solution                              | Dissolutional lowering of surface; up to 1 000 m across, 100 m deep.   |
|                              | Collapse                              | Rock roof failure into cave; up to 300 m across, 100 m deep.   |
|                              | Caprock                               | Soil collapse into soil void above bedrock fissure; up to 50 m across, 10 m deep.  |
|                              | Dropout                               | Down-washing of soil into bedrock fissures; up to 50 m across, 10 m deep.  |
|                              | Suffusion                             | Soil infilling of earlier sinkhole in rock; up to 300 m across, 100 m deep.  |
|                              | Buried                                |  |
| Caves in insoluble rocks     | Sea caves                             | Marine erosion of fractures, faults and weak rock horizons.  |
|                              | Sandstone caves                       | Sandstones can weather to sand followed by piping.   |
| Landslide fissures           | Landslide fissures                    | Narrow, sub vertical fissures at the head of larger landslides; can become bridges.  |
| Gullies formed by cambering  | Open                                  | Periglacial conditions needed for formation; wide fissures (up to 10s of metres) open up as blocks of competent rock slide downhill.                   |
|                              | Covered                               | Can become bridges by soil and debris leaving passages 1 m to 2 m wide   |
| Other features               | Soil pipes                            | Ephemeral features in some cohesive soils.   |
|                              | Frost involutions; ice wedges         | Small-scale features in soils in periglacial environments; almost always infilled. Hidden by soil veneer. Circular features 100 mm to 2 m in diameter. |
|                              | Glacial over-riding fissures          | Linear troughs up to 2 m wide and 50 m long  |
|                              | Pipes, collapses and pseudo-sinkholes |  |
| <b>Anthropogenic</b>         |                                       |  |
| Mining by partial extraction | Coal mines                            | Depths from less than ten to hundreds of metres, extraction can be over 70% in some cases.   |
|                              | Industrial mineral mines              | Mines stable/meta-stable at first, but subsidence eventually takes place; this could take more than 100 years to complete.                             |
|                              | Building stone mines                  |  |
|                              | Evaporite mines                       |  |
|                              | Metalliferous mines                   |  |
| Mining by total extraction   | Coal mines                            | Depths from tens to hundreds of metres.<br>Extraction 100%.<br>Voids can be left after subsidence.<br>Subsidence could take many years to complete.    |

Table F.1 Principal types of void (2 of 2)

| Void type                            | Subdivisions  | Characteristics   |
|--------------------------------------|---|---|
| Salt extraction                      | Partial extraction  | Wild brine pumping caused much subsidence.  |
|                                      | Dissolution mining  | Modern mining designed to avoid subsidence.<br>Void might be left filled with saturated brine.<br>Some subsidence might still take place. |
| Groundwater abstraction and disposal | Groundwater resources supplies                            | Can cause the reactivation of faults and fissures.  |
|                                      | Fluid waste disposal in boreholes                         |   |
| Mining induced fault reactivation    | Moorland slopes   | Up to 3 m wide and 500 m long.  |
|                                      | Hillside slopes   | Can form complex interconnecting voids, or single isolated voids.<br>Sometimes bridges by surface vegetation or jointed rock.             |
| Vein stoping                         | Various metalliferous minerals                            | Stopes usually a few metres to tens of metres wide and high angle.  |
|                                      |   | Depths to hundreds of metres or more.<br>Subsidence could take more than 100 years to complete.   |
| Surface mining                       | Quarries  | Pits in soils and softer rocks have inclined walls.   |
|                                      | Pits  | Quarries in stronger rocks have steep to vertical walls.<br>Both might be backfilled with natural materials or waste.                     |
| Mine entrances                       | Shafts  | Many not recorded.  |
|                                      | Adits   | Can be well capped, poorly capped or bridged by debris.   |
|                                      | Drifts  | Can be unstable, particularly near entrance and when shallow.   |
|                                      | Headings  |   |
|                                      | Roadways  |   |
| Engineering                          | Tunnels   | Linear, 1 m to 10+ m in diameter.   |
|                                      | Underground storage chambers                              | Shallow and deep; might be unrecorded.  |
|                                      | Basements   | Irregular; usually in stiffer soils or weaker rocks; usually at shallow depth.  |
|                                      | Utilities and pipelines                                   | Underground storeys of buildings.<br>Small voids less than 1 m to 5 m.  |
| Military sites                       | Bunkers, shelters and storage facilities                  | Vary considerably in size, from less than 1 m <sup>2</sup> to hundreds of metres in size, depending upon the design requirements.         |
|                                      | Munitions and explosive manufacturing and test facilities |   |
| Archaeological sites                 | Graves  | Can vary from centimetres to tens of metres in size; often no record; might have deteriorated and be hard to identify.                    |
|                                      | Hypocausts Wells  |   |
|                                      | Kilns   |   |
|                                      | Shafts  |   |
|                                      | Other underground structures                              |   |

### F.3 Natural voids

#### F.3.1 Soluble rocks

The dissolution of soluble rocks such as halite, gypsum, anhydrite, chalk and limestone can lead to a variety of types of natural voids. Natural dissolution processes are generally slow in limestone and chalk and such voids have typically developed over long periods of time, frequently thousands of years. In suitable hydrogeological situations, dissolution of gypsum can be rapid and dissolution of salt extremely rapid. Many dissolution voids are related to periglacial processes, but the triggering mechanisms of collapse commonly relate to localized infiltration.

Dissolution usually affects limestone, chalk, rock salt and gypsum-bearing rocks and these lithologies contain the majority of natural voids in the United Kingdom. Dissolution features associated with soluble rocks are, therefore, not uniformly distributed throughout the United Kingdom. Consideration of lithology and the processes involved in void formation assists in assessing the susceptibility of a particular area to contain such natural voids and their influence on a particular project.

Rocks are progressively dissolved on contact with water, forming a wide geometrical variety of voids. This process, although more dominant in the upper zones of soluble rocks, can result in the formation of voids at depth by dissolution along discontinuities. Dissolution enables the formation of a variety of void types including cave systems, open fissures or enlarged joints, sinkholes, dissolution breccias, "wet rockhead" and pipes. "Karst topography", the characteristic landscape formed as a result of dissolution processes, could be formed. Such karst might comprise grikes and dykes of exposed limestone pavements or by gently undulating dry valley terrain, e.g. the Pennines. The potential hazards represented by this and other sources of natural voids are summarized in Table F.2.

A map of the various karst areas in the UK is included at: [www.bgs.ac.uk/caves](http://www.bgs.ac.uk/caves) [last viewed 24 June 2015].

Table F.2 Natural voids: potential hazards (1 of 2)

| Potential hazard   | Natural voids |               |                   |                 |                     |
|--|---------------|---------------|-------------------|-----------------|---------------------|
|  | Soluble rocks | Mass movement | Glacial and frost | Action of water | Faults and fissures |
| Near surface voids into which overlying ground collapses might generate voids at the ground surface.   | X             |               |                   |                 |                     |
| Voids can collapse, resulting in subsidence of the land above. More commonly, changes in ground or surface water flow can flush out existing sediment-filled fissures, sinkholes and caves, leading to subsidence. This causes the formation of circular cylindrical or conical depressions at the ground surface known variously as sinkholes, swallow holes, shake holes or dolines. | X             |               |                   |                 |                     |
| Preferential flow of water (and high groundwater level) can control the hydrogeology of wide areas and might represent a transmission pathway for contamination.<br>Preferential flow of water (and high groundwater level) can control the hydrogeology of wide areas and might represent a transmission pathway for contamination.   | X             |               |                   |                 |                     |
| Where rocks become partially dissolved they might become brecciated, with a marked reduction in intact rock and rock mass strength characteristics.  | X             |               |                   |                 |                     |
| In areas of rock salt the long-term dissolution processes can result in the formation of "wet rockhead", a "solution" surface below which the horizons of rock salt remain intact and above which they are dissolved.  | X             |               |                   |                 |                     |
| Depth to rockhead in areas of karst might be variable and unpredictable.   | X             |               |                   |                 |                     |
| The generation of a failed mass of material containing a high volume of voids. Such materials might have a high potential to collapse following the re-orientation and reduction in the void spaces or might potentially flow under the action of water.   |               | X             |                   | X               |                     |
| Migration of voids generating localized loss of ground and voids at the ground surface.  | X             | X             | X                 | X               |                     |
| Subsidence   | X             | X             | X                 | X               | X                   |
| Linear cracks (fissures or breaks) in soils or rock either formed where the materials have detached totally, or where the tensional stresses on the slope have formed tension cracks behind an unstable slope face. Such features might become blocked or choke filled at the ground surface and represent a hazard to existing or proposed development above.                         |               | X             | X                 |                 |                     |
| Preferential migration pathways for hazardous gases and groundwater.   | X             |               |                   |                 | X                   |

Table F.2 Natural voids: potential hazards (2 of 2)

| Potential hazard  | Natural voids |               |                   |                 |                     |
|---|---------------|---------------|-------------------|-----------------|---------------------|
|   | Soluble rocks | Mass movement | Glacial and frost | Action of water | Faults and fissures |
| Loss of ground generating voids at the ground surface.                              |               |               |                   |                 | X                   |
| Loss of drilling fluids during tunnelling and other forms of "no dig" technologies. | X             |               |                   |                 | X                   |

### F.3.2 Mass movement

Mass movement is a generic term for downslope movement of soil, rock or a mixture of both materials under the force of gravity. The type of mass movement occurring at a particular location is dependent on various interrelated factors including slope angle, in-situ material characteristics, material mass characteristics, groundwater regime, loading conditions and the influence of external works, e.g. engineering activities. The result of mass movement is a failed mass of material, with the extent and characteristics of the failed mass a function of the type of mass movement. The causes of mass movement are varied and frequently interlinked.

### F.3.3 Glacial and frost

During the Quaternary period significant parts of the UK were affected by cyclical periods of extreme cold weather (glaciations) followed by periods of warmer weather (interglacials). Since the end of the last glaciation, less extreme cyclical variations in temperature have occurred on a seasonal basis. There are numerous effects on soils, rocks and geomorphology associated with these climatic variations. Many of these do not generate voids of a significant size, but generate metastable soil structures, e.g. some loessic deposits.

The effects of freezing of water in discontinuities and voids, with a cyclical freeze-thaw process, generates extensional forces in these materials with the overall effect being the formation of voids, or the increasing in size of pre-existing voids. The scale of such processes varies between the smaller disintegrations due to frost shatter to larger scale displacements involved in foundering, cambering and valley bulging. Certain rocks are more susceptible to frost shatter, e.g. chalk.

### F.3.4 Action of water

Surface and subterranean water flows can cause soils and rocks to become unstable, either generating voids by dissolution or physical weathering, or forming resultant deposits potentially containing voids. The chemical and physical weathering processes acting on rocks can be significantly increased by the action of water. The presence of pre-existing discontinuities, representing zones of increased permeability and water movement and preferential water flow, result in concentrated water flows.

Where the stratigraphy contains soluble rocks, such as limestone or chalk, dissolution processes over significant time periods result in the formation of natural cavities. In marine settings, the erosion of non-soluble rocks can result in the formation of sea caves and in such settings the location and lineation of the caves is frequently associated with pre-existing structural discontinuities and low strength horizons in the rock strata. Erosion of soils could result in the formation of scour hollows, which might represent areas of reduced density, voided ground.

### F.3.5 Faults and fissures

Voids might be generated where compressive and tensional tectonic forces have broken the rock strata. This can result in either the formation of fault planes or zones (possibly containing fault breccias) or in open rock fissures. Faults can occur on a variety of scales from less than a metre to many hundreds of metres, with the nature of the voids generated along and adjacent to the fault similarly variable. Fault zones can contain a high percentage of voids or the voids might be infilled with finer grained materials and clay "gouge". Similarly, the development of fissures or breaks in rock which have not laterally moved, can result in the formation of vertical or steeply inclined voids, either single features or a number of features within discrete fissure zones.

## F.4 Anthropogenic (man-made) voids

### F.4.1 General

The range of anthropogenic (man-made) voids and the potential hazards are summarized in Table F.3.

Information on hazardous coal mine gases can be found in the Coal Authority et al., 2012 [5] publication.

### F.4.2 Construction and building

Previously developed, brownfield sites might have contained below and above ground structures, which following their demolition and the reworking or remediation of the site could represent sources of voids. Significant types of voids include partially subsided and collapsed basements, ducts, undercrofts, access tunnels, demolition arisings, cavities and those formed by subsidence beneath structures. The voids might be undocumented and be developed over for various uses, often including less sensitive uses such as car parking and open space. Geotechnical failure processes arising from construction activities, e.g. tension cracks formed as a result of slope failure, might also represent sources of voids.

Asbestos was often placed within above and below ground structures as insulation and can often be missed by asbestos building surveys or if an underground structure has been sealed off. Extreme caution needs to be shown if investigations encounter such structures.

### F.4.3 Infrastructure

When infrastructure containing voids is operational, these voids are generally maintained to ensure that they do not represent hazards to overlying development. Proposed new developments might, however, represent sources of hazard to existing infrastructure, and on that basis their identification and investigation can be critical. Old or redundant infrastructure can represent a source of voids in the ground, particularly where there is little information or knowledge about these features. In terms of voids, the principal sources associated with infrastructure comprise ducts, drains, sewers, pipelines, tunnels, shafts, wells, underground canals, old bridges and similar structures.



Table F.3 Anthropogenic voids: potential hazards

| Potential hazard   | Anthropogenic (man-made) voids |                |        |                |        |                |
|--|--------------------------------|----------------|--------|----------------|--------|----------------|
|  | Construction and building      | Infrastructure | Mining | Waste disposal | Graves | Military sites |
| The generation of a failed mass of material containing a high volume of voids which might be water-filled. | X                              |                | X      |                |        |                |
| Unexpected and unpredictable collapse and loss of ground forming holes at the ground surface.              | X                              | X              |        |                |        |                |
| Accumulations of explosive and/or asphyxiant gases.  | X                              | X              | X      |                |        |                |
| Minewater rebound, i.e. rising minewater levels.   |                                |                | X      |                |        |                |
| Water release from voids and/or drainage channels.   | X                              | X              | X      |                |        |                |
| Health and safety hazards associated with site occupiers falling into uncovered inspection chambers.       |                                | X              | X      |                |        |                |
| Proposed site developments and their investigations damage live services, tunnels, etc.                    |                                | X              |        |                |        |                |
| Mining subsidence.   |                                |                | X      |                |        |                |
| Collapse and settlement of mine entries.   |                                |                | X      |                |        |                |
| Emissions of mine gas.   |                                |                | X      |                |        |                |
| Tip fires and spontaneous combustion.  |                                |                | X      |                |        |                |
| Settlement (for example of infill to surface mines).   |                                |                | X      | X              | X      | X              |
| Generation of landfill-type gases.   |                                |                |        | X              | X      |                |
| Contamination.   | X                              | X              | X      | X              | X      | X              |
| Spontaneous combustion and fire.   |                                |                | X      | X              |        |                |
| Collapse and loss of ground.   |                                |                |        |                |        | X              |
| Explosion.   |                                |                |        |                |        | X              |

#### F.4.4 Mining

Different methods of mining, e.g. underground (partial and total extraction), solution (controlled and uncontrolled), stoping, surface mining and quarrying can all generate voids and potentially reactivate geological faults. The voids might be associated with the actual mine working, the mine entrance, i.e. shaft, adit, etc., or be related to the nature of the backfill in the abandoned working, e.g. non-engineered fill and voids within backfill to abandoned surface mineral workings. Abandoned mine workings might be extremely old, frequently with little or no obvious surface evidence of former mining activities being present, with the surface mine infrastructure generally completely obliterated. Depending upon the age of the mining, there might be no formal records of the former mining activities and the workings could be unrecorded.

CIRIA SP32 [170] (at the time of publication this was being revised by CIRIA as report reference RP940) provides a detailed account of mining activities in the UK, methods of mining, associated hazards, appropriate methods of investigation, and mitigation options. CIRIA RP940 is intended to include a comprehensive list of available information relating to historical mining of all types across the British Isles.

Attention is drawn to the need to consult the Coal Authority when investigation works are to enter mine working in the UK.

#### F.4.5 Waste disposal

Certain waste materials have a high void ratio and in certain situations they might be prone to settlement (particularly differential settlement), loss of ground and collapse. The void ratio of such deposits can vary over time due to compaction and consolidation processes and, where organic materials are present, by biological degradation.

Mine spoil tips are scattered throughout former/current mining areas across the UK, and such materials might contain voids, with the extent of the voids being a function of material type, method of tipping, age and nature of any post deposition activities. Old surface excavations, opencast sites and quarries can also contain less well-controlled backfill and non-engineered fill. Although much of these backfills are composed of reworked natural soils and rock (excavated during the mining process), prior to the formal licensing of waste disposal activities waste materials in accordance with the Control of Pollution Act 1974 [171], e.g. domestic and industrial wastes, might also have been incorporated into the backfill. In rural areas diseased livestock have also been recorded in former excavations and quarries.

#### F.4.6 Graves

Over time, buried organic remains undergo biological degradation potentially resulting in the formation of voids, loss of ground or settlement. These can include ancient archaeological graves and burials, either recorded or unrecorded, or more recent graves and cemeteries. It is rare that ground investigations unknowingly encounter recent graves since the cemetery boundaries are generally well recorded; however, situations have occurred where ground investigations have encountered recent graves without cemetery boundaries.

#### F.4.7 Military sites

Abandoned, and long forgotten, military sites can potentially contain voids. An additional hazard associated with such sites is the presence of explosive or other harming substances within the voids. Potential sites can be associated with underground storage areas and tunnels; sites of underground bunkers associated with munitions manufacture, storage and testing; civil defence structures; basements; shelters; tunnels; and overfilled gun emplacements.

## **F.5 Ground investigation procedures**

### **F.5.1 Stage 1: Desk study**

#### **F.5.1.1 General**

The susceptibility of the site to contain various geohazards, including voids, is usually revealed through the completion of the desk study. In some cases the scale of any potential voids and associated hazards can be estimated with some accuracy from the desk study. Only when the nature of the potential voids affecting the site have been identified can an assessment be made of the ground investigation techniques most appropriate for their investigation. The information obtained from the desk study is also used to identify health and safety hazards associated with the proposed investigations, and their mitigation, to ensure the safety of site staff, members of the public and site occupiers as well as ensuring the protection of property.

#### **F.5.1.2 Sources of information**

Annex A to Annex E give sources of information which can be obtained and reviewed (see C.9 in particular).

#### **F.5.1.3 Field reconnaissance**

During the inspection, the site is examined to identify any features, natural or anthropogenic, which might be associated with voids. Such features include crown holes, depressions, changes in ground slopes for evidence of brine runs or collapsed workings, demolished mine buildings, mining waste and damage to existing structures.

*NOTE* Those making the site inspection need to be made fully aware of the risk of cavities and appropriate protective measures deployed and used.

#### **F.5.1.4 Reporting**

The susceptibility to geohazards associated with the presence of voids is to be identified and recommendations given for ground investigation necessary to further assess the risks to enable the progression of design and costing of any site remediation works. The early mitigation of relict coal mining risk is required to be demonstrated by a developer at planning application stage. The UK Coal Authority, as one of the statutory consultees to the planning process, require planning applications in areas deemed to be at increased risk from historical coal mining activities to be accompanied by a Coal Mining Risk Assessment (CMRA) prepared in accordance with their guidance documents.

### **F.5.2 Stage 2: Ground investigation**

#### **F.5.2.1 Review of project requirements**

To ensure that the ground investigation provides all the required information for design, it is critical that the project requirements are reviewed, particularly the preliminary assessment of the geohazards. Only when this review is completed can the full extent, scope and design of the ground investigation be determined.

**F.5.2.2 Consideration of conceptual model**

Typical questions to ask:

- What voids are expected to be present at the site?
- What is the anticipated size, nature or frequency of likely voids beneath the site?
- How extensive are the voids likely to be?
- To what depths might voids be expected?

The answers to these questions, in conjunction with a good understanding of the nature of the likely geohazards, enable the areas of investigation and investigation strategy to be determined. Non-intrusive investigative techniques such as geophysics can be used as preliminary work to help optimize any subsequent intrusive investigation.

The number of investigation points (trenches, boreholes, etc.) required depends on various factors including the likely nature of the void or feature being investigated; the type and extent of the proposed structure(s); the site conditions; the foundation design envisaged; and the conjectured geology and geological structure. The maximum depth to which exploratory boring is carried out is determined by the nature of the structure(s) proposed and by the nature of the proposed hazard, geology, geological structure, etc.

**F.5.2.3 Methods of ground investigation**

Methods to investigate for the potential presence of voids, both invasive and non-invasive, are covered in detail in Sections 3, 4 and 5.

## Annex G (informative)

### G.1

# Integrated investigations

## General

The degree of integration of geotechnical investigations with other studies (such as contamination or archaeological investigations) is based on the findings of the desk study and field reconnaissance.

It is important that appropriate expertise is applied to the design and execution of integrated investigations and that those involved do not go knowingly or otherwise beyond their expert capability.

Any integrated field investigation needs to be designed so that it does not compromise the requirements of any aspect of the integrated investigation.

Integrated geotechnical, contamination and ground gas investigations are the most common form of integrated investigations. However, linking the field investigation with other types of studies can also be appropriate in some circumstances. In particular, the ecological survey of a site and surrounding area could indicate contamination on the basis of observed impacts on flora. Geotechnical, archaeological and contamination investigations can share information from geophysical survey work (see Section 5 and BS 10175).

Whilst the primary guidance on the investigation of potentially contaminated sites is provided in BS 10175, and on investigations for ground gas in BS 8576, it is important to recognize that these in turn refer to a number of standards in the BS ISO 10381 series (to be replaced by the BS ISO 18400 series, in preparation).

*NOTE BS ISO 18400-102, which is to replace BS ISO 10381-2, is intended to provide guidance on the selection and application of sampling techniques for soil quality investigations (it covers agricultural and near-natural sites as well as potentially contaminated sites). It is intended to complement and be consistent with BS EN ISO 22475-1 as appropriate although the terminology and approach inevitably differ somewhat given the different contexts in which they are intended to be used.*

### G.2 Integrated contamination and geotechnical investigations

Integrated contamination and geotechnical investigations have the following advantages (which result in lower costs compared to undertaking separate field investigations):

- a) simplified project management;
- b) common use of equipment and procedures;
- c) exploratory holes can be used for more than one purpose;
- d) joint health and safety procedures can be established;
- e) joint environmental protection procedures can be established;
- f) integrated consideration of resultant data; and
- g) reduced project duration (compared to sequential contamination and geotechnical investigations).

As noted in G.1, any integrated field investigation needs to be designed so that it does not compromise the requirements of the various aspects of the investigation.

Geotechnical specialists involved in the design and execution of integrated contamination and geotechnical investigations need to be aware of both the different contexts in which contamination investigations often take place and the important differences in technical approaches, which, if not properly understood, could lead to poorly designed and executed investigations, intervention by regulators, and additional costs and liabilities for the client. Important differences include:

- whilst sharing many requirements, the two desk studies and site inspections do require different types of information and different expertise to be applied to the examination and synthesis of the information so as to form appropriate initial hypotheses about the nature and possible location of key physical, geotechnical and contamination features (i.e. conceptual site models and ground models);
- contamination investigations are often the subject of regulatory scrutiny and reports are often in the public domain; and
- the requirements for sampling (e.g. number of sampling locations, number of samples from each location and types of samples to be taken as well as sampling protocols) are usually markedly different from those for geotechnical investigations.

Both contamination and geotechnical investigations can be required in order to discharge conditions attached to Planning Permissions. Regarding geotechnical issues these usually relate to potential unacceptable risks from features such as: historical mining, karst and slope instability. In these cases, investigations for both contamination and geotechnical both follow similar procedures and discharging conditions often require staged written approvals by the local planning authority (LPA) as the work progresses. For example, approval of:

- a preliminary investigation (desk study, field reconnaissance and preliminary risk assessment) report;
- the design of a planned intrusive investigation;
- the report on the intrusive investigation and interpretation of results including a more detailed risk assessment;
- where risks are considered unacceptable, a proposed remediation scheme; and
- a verification report once remediation is completed.

Reports are consequently subject to careful scrutiny and are likely to be posted on the LPA's website or otherwise made available to the public. In many instances, the LPA consult the Environment Agency (or equivalents) before making a decision about the acceptability of a report or proposal.

BS 10175 recommends that any conditions or similar formal requirements are provided in reports together with any key correspondence with regulators.

If, for any reason, a planning application is refused and the client appeals, any information or opinion regarding the contamination aspects of the site might have to be defended in public or at least before the Planning Inspector at an informal hearing. Those carrying out such work, therefore, need be confident that they can justify their claim to expertise.

Guidance on desk studies and field reconnaissance is provided in Section 2 of this British Standard and in BS 10175.

Combining the desk studies and field reconnaissance for the two aspects of the investigation can provide significant savings in cost and help to provide a better informed initial conceptual model as a result of the two areas of expertise being brought to bear. It is essential if this work is carried out by a single person, that they have the requisite expertise and experience. If there is any doubt whether the person carrying out the field reconnaissance is properly able to address both contamination and geotechnical aspects then it would be better carried out by two appropriately experienced people, who can inform and consult each other.

A geotechnical investigation in which a few incidental samples have been taken does not form a sound basis for assessing contamination on a site although they might provide some useful information.

Guidance on sampling for contamination is provided in BS 10175. Particular attention is to be paid to the guidance regarding sampling depths and the need for a systematic approach. Failure to take enough samples of the right type in the various zones of the site and then to carry out appropriate analysis and testing can result in a report being rejected by a regulator.

Guidance is also given in BS 10175 on the proper choice of sampling containers for samples for chemical analysis and on such issues as packaging, preservation and transport. Failure to observe good practice could lead to loss of the integrity of the samples including, for example, chemical or microbial degradation of contaminants and loss of volatile organic compounds (VOCs).

Analytical strategies need to be developed with care, taking into account the history of the site. Failure to do so can not only lead to rejection of a report by the regulator because key potential contaminants have not been considered, but can also result in unnecessary additional cost and time. General suites of determinands embracing a wide range of possible contaminants cannot be specified unless this can be justified on technical grounds. It can mean that the analysis of each sample is unnecessarily expensive inducing pressure to reduce the number of samples analysed to contain costs. It is better to analyse more samples for a carefully chosen set of determinands than a few samples for a wide range of potential contaminants, some of which are highly unlikely to be present. However, where more than one phase of intrusive investigation is considered likely, a broader "screening" process might be beneficial in the initial stage so as to better inform the detailed design of the subsequent investigation and analytical stage. Proving a site "clean enough" for a specific purpose can demand much more sampling and analysis than that needed to show the converse situation.

*NOTE 1 Characteristics of investigations for contamination carried out by poorly informed geotechnical specialists often include: too few sampling locations, insufficient samples being taken from each location with those taken appearing to have been taken at random depths from different holes, absence of data on surface and near-surface soil.*

*NOTE 2 The analytical methods employed in suites for wide ranges of contaminants might not be as accurate or precise as those employed for discrete determinands or types of determinands, e.g. determinations of speciated polycyclic aromatic hydrocarbons (PAHs) by GC MS tend to be more accurate than those determined as part of a SVOC (semi volatile organic compounds) suite.*

### **G.3 Integrated geotechnical, groundwater and ground gas investigations**

BS 10175 provides guidance on investigations of the water environment during investigations of potentially contaminated sites and BS 8576 provides guidance on ground gas (permanent gases and VOCs) investigations on all types of site.

The formation of boreholes for geotechnical purposes offers the opportunity to install gas, groundwater or combined ground gas and groundwater monitoring wells, with possible reductions in overall costs and possibly time savings for the overall investigations. However, whilst installation of monitoring wells on an ad-hoc basis can be simple, any detailed investigation might require the approval of regulators in advance and the results are often placed in the public domain. All the strictures regarding combined geotechnical and contamination investigations apply, e.g. the need for employment of appropriate expertise in the design and implementation of the integrated investigation and the need for the objectives of the two types of investigation not to be compromised.

Wells installed in geotechnical boreholes provide an opportunity to obtain data on groundwater quality but are not necessarily located where contamination is most likely. Also they might not be located so as to enable the direction of groundwater flow, and its gradient, to be determined. Thus, except when data is being collected on an ad-hoc basis, integrated investigations are likely to require formation of boreholes additional to those required for geotechnical purposes. Similarly, detailed investigations for ground gas are likely to require formation of additional boreholes.

*NOTE Although it is frequently possible to use a single well for monitoring both groundwater quality and for ground gas, such wells are seldom suitable when carrying out detailed surveys for VOCs (see BS 8576).*

## G.4 Case study – Integrated contamination and geotechnical investigation for planned residential development

### G.4.1 General

Planning permission had been granted for the erection of three detached houses with individual gardens on the plot currently occupied by a single vacant pre-1938 detached house, which is to be demolished prior to construction of the new houses. The existing and planned layouts are shown in Figure G.1 and Figure G.2 respectively. The planning permission did not contain a condition relating to contamination but it was deemed desirable to carry out an investigation in view of the history of the site (old residential gardens are often contaminated by, for example, bonfire residues or fuel storage impacts and consequently have elevated concentrations of contaminants at shallow depths) and in order to provide information to satisfy NHBC requirements (see also G.4.5).

The overall investigation comprised:

- a desk study and field reconnaissance (termed a “preliminary investigation” in BS 10175) carried out in accordance with BS 10175 and BS 5930 and followed by preparation of a preliminary [environmental] risk assessment;
- a combined geotechnical and contamination intrusive field investigation in which samples of soil were taken for chemical analysis and geotechnical testing.

The principal objectives of the investigation were to:

- determine whether there is anything in the history of the site or that of neighbouring land that might have resulted in the site becoming contaminated;
- collect information on actual contamination (if any) on the site through an intrusive investigation;
- make an assessment of the implications for the proposed development including development of a “conceptual site model” describing site conditions and the potential for any contamination to affect future site users and other potential receptors;



- provide an outline remediation strategy if required by the findings of the investigation; and
- determine the nature and properties of the ground at the site to permit the design of foundations for the proposed houses.

*NOTE* "Contamination" is used here to mean the "presence of one or more potentially harmful substances or agents at above natural background concentrations as a result of human activity" (this is similar to the definition in BS 10175). The use of the term in this way does not imply that harm is being, or might be, caused by the contamination, i.e. one of the conditions for land to be statutorily designated as "contaminated land". It is the purpose of the assessment to be carried out on completion of the field investigation to evaluate the potential significance of any contamination that might be present.

#### G.4.2 Desk study

Documentary information was obtained in the form of:

- Ordnance Survey maps for the period 1875 to 2011;
- geological maps for the area;
- the Environment Agency's groundwater vulnerability map for the area;
- the regional hydrogeological map; and
- borehole logs from the BGS.

Information on the Environment Agency's website was also taken into account.

Potential sources of information not consulted include the local planning authority's historical planning records (other than via the council's website), old street directories and aerial photographs.

#### G.4.3 Field reconnaissance

An initial site visit was made by the geotechnical engineer who had participated previously in many integrated investigations. He was able to make observations on the layout and general appearance of the site, consider the best way to investigate the site for both purposes, consider such factors as ease of access, and make a photographic record of the site. His observations were supplemented by the environmental specialist during the course of the fieldwork.

#### G.4.4 The site

The site was in a semi-rural residential area with a large detached pre-1938 house surrounded by a large level garden about 0.27 ha in size (about 75 m long by 42 m at its widest point). Most of the ground was laid to lawn but there was evidence of old flower beds and an old greenhouse. The house appears to have been heated by gas although solid fuel might have been the main source in earlier years (the remnants of a coal bunker were found near to the house).

The old greenhouse was located at the end of the site furthest from the house. The old OS maps showed the greenhouse as being present from before 1938 until at least the 1980s. There was little direct evidence for its former presence apart from a small amount of broken glass on the surface of one of the old flower beds. A neighbour reported that the wood-framed greenhouse had been demolished about twenty years previously and that it might have had a commercial use. He thought that the wood from the frame had been burned on site.

There was also anecdotal information that there had once been a garage built from asbestos-cement sheeting close to the entrance of the site but there were no obvious signs of this to be seen.

No nearby (i.e. off-site) activities that might have led to contamination of the site were identified.

The geological map indicated that the site was underlain by Beaconsfield Gravel comprising sand and gravel which in turn overlies the Seaford Chalk Formation and Newhaven Chalk Formation (undifferentiated). The site is in an area in which solution features have been encountered.

The site was concluded to be in a “sensitive” area in terms of any potentially contaminating activities due to the chalk being classified as a Principal Aquifer and the overlying soils classified as soils of High Leaching Potential (HU). The site is within a Total Catchment Source Protection Zone. There are no nearby surface water features and the site is not in an area subject to flooding.

#### **G.4.5 Potential for contamination and related problems**

The probability of significant contamination of the land where the houses were to be built was considered to be low except possibly where the greenhouse had been. However, the garden had been in use for over 70 years and it was considered likely, therefore, that some contamination would be present as a result of aerial deposition, deposition of soot and coal ash, burning of domestic wastes on bonfires, including, for example, painted and chemically treated wood and linoleum (pigments containing, for example, zinc were commonly used), corrosion of galvanized metals (zinc) and flaking lead paint, etc. The most common contaminants in domestic gardens are arsenic, lead, copper, zinc and polycyclic aromatic hydrocarbons (e.g. present in ash and soot). The older the property, the greater the amount of contamination that is likely to be present. In a large garden there might be small areas heavily impacted by such activities and events but overall the impact (in terms of relative scale) is probably less than in a small garden.

The environmental specialist identified through past experience that the burning of the wooden-frame of the old greenhouse might have led to contamination of the ground in the vicinity with lead and zinc. There was also a possibility that it had been heated by a coal-fired boiler providing another source of ash that might have been distributed around the garden to form paths etc.

As noted in **G.4.4**, there was anecdotal information that there had once been a garage built from asbestos-cement sheeting close to the entrance of the site but there were no obvious signs of this to be seen.

No evidence was found that natural concentrations of potentially harmful substances (e.g. arsenic) are elevated in the area.

#### **G.4.6 Preliminary assessment**

The hazards posed by the most probable potential contaminants are summarized in Table G.1. Those considered to be most likely to be relevant for the planned development were considered to be potentially toxic elements such as lead, polycyclic aromatic hydrocarbons (PAHs) and phytotoxic zinc.

Table G.1 Identification of principal potential hazards relating to contamination

| Contaminant(s) [sources]                           | Principal hazard/reasons for concern (including potential receptors) | Comments  |
|--|--|---|
| PAHs and toxic elements including arsenic and lead | Potentially harmful to human health                                  | Near-surface sampling required in garden area.<br>Potential risks to future site occupants and other human receptors.   |
| Copper, nickel and zinc                            | Toxic to plants  | Concentrations might be elevated.<br>Near-surface sampling required.  |
| PAHs and toxic metals                              | Potential groundwater and surface water contaminants                 | Negligible risks  |
| Petroleum hydrocarbons                             | Potential groundwater and surface water contaminants                 | No evidence for oil tanks etc. found.<br>Negligible risks.  |
| Asbestos   | Some forms are proven carcinogens                                    | Investigation not required.<br>Anecdotal information that there had been an asbestos-cement structure on the site – sampling required in this part of the site. |

#### G.4.7 Fieldwork

The fieldwork was carried out with both the geotechnical engineer and the environmental specialist on the site. All logging was carried out by the geotechnical engineer.

Ten trial pits were formed. The trial pit locations were chosen taking the proposed layout into account so that samples for chemical analysis could be taken as far as practical from both the future front and rear garden areas of each house (there was limited access in places). Two pits were located within the footprint of the old greenhouse and one in the gravel drive at the front of the existing house.

Five of the trial pits at locations chosen by the geotechnical engineer were formed to about 2.5 m to enable the ground to be inspected and samples taken for geotechnical testing. The remaining five pits were formed to depths of up to about 1.0 m. The trial pit locations are shown in Figure G.2.

The trial pits exposed varying thicknesses of topsoil over sandy clay with sand and gravel at greater depths. Overall, twenty four samples were taken for chemical analysis from the topsoil and underlying sub-soil from depths of 0.1 m to 1.2 mbgl from the ten trial pits. Samples were taken from the near-surface top-soil and from within the range 0.4 m to 0.6 m from each trial pit.

In addition, several surface and near-surface samples were taken by hand from the assumed location of the old asbestos-cement garage.

#### G.4.8 Analytical strategy

The samples were analysed for acidity (pH), a range of potentially harmful elements, and polycyclic aromatic hydrocarbons (PAHs).

The samples from the assumed location of the old asbestos-cement garage and a number of other of the top-soil samples were screened for asbestos fibres (no asbestos-cement fragments were seen during sampling).

### G.4.9 Geotechnical testing

Three samples were taken for geotechnical testing. Tests were carried out for natural water content, liquid and plastic limit, pH, sulfate content (total and water soluble).

*NOTE* If a windowless percussive sampling rig had been used it would have been possible to obtain SPTs.

Figure G.1 Layout at the time of the investigation

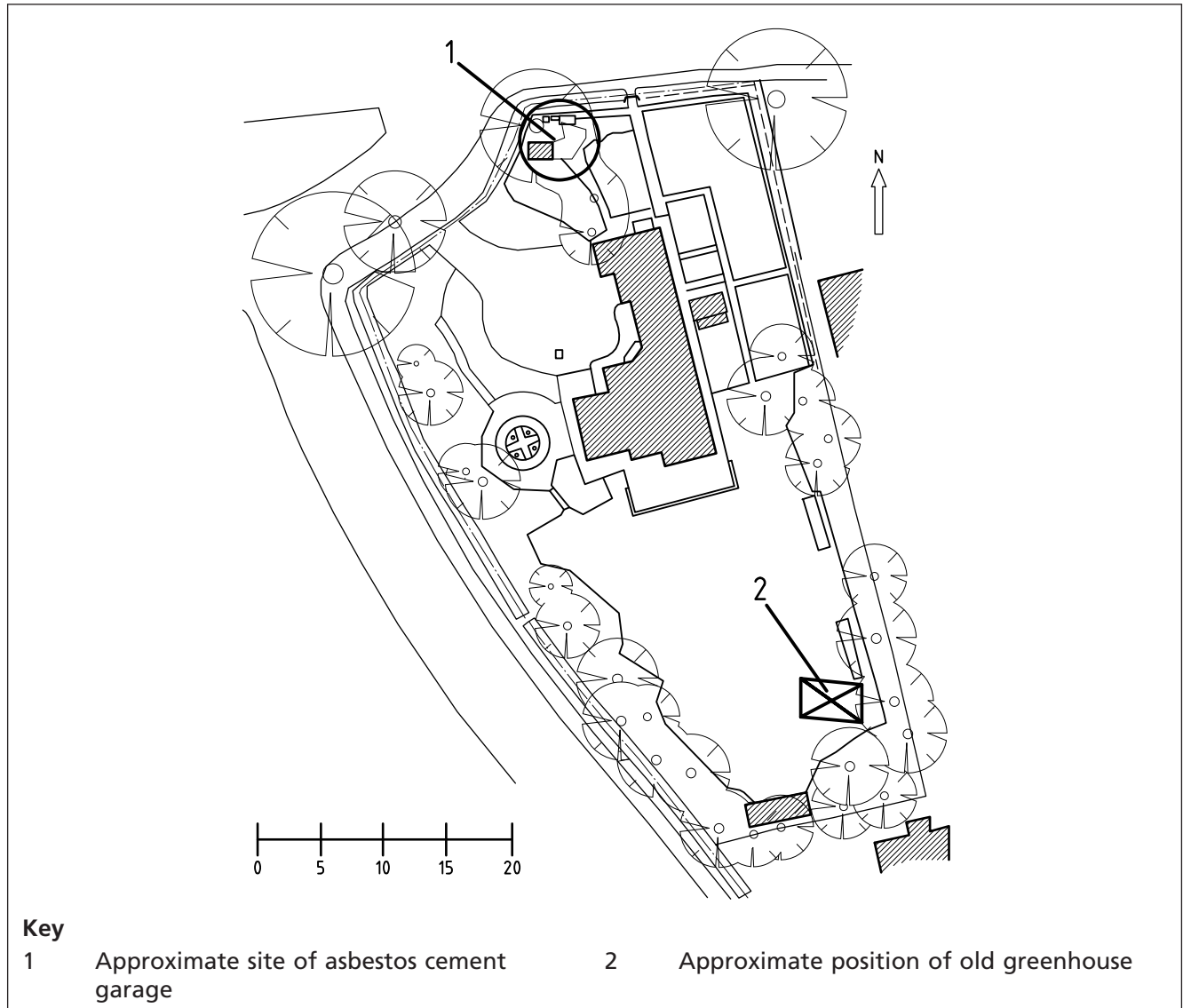
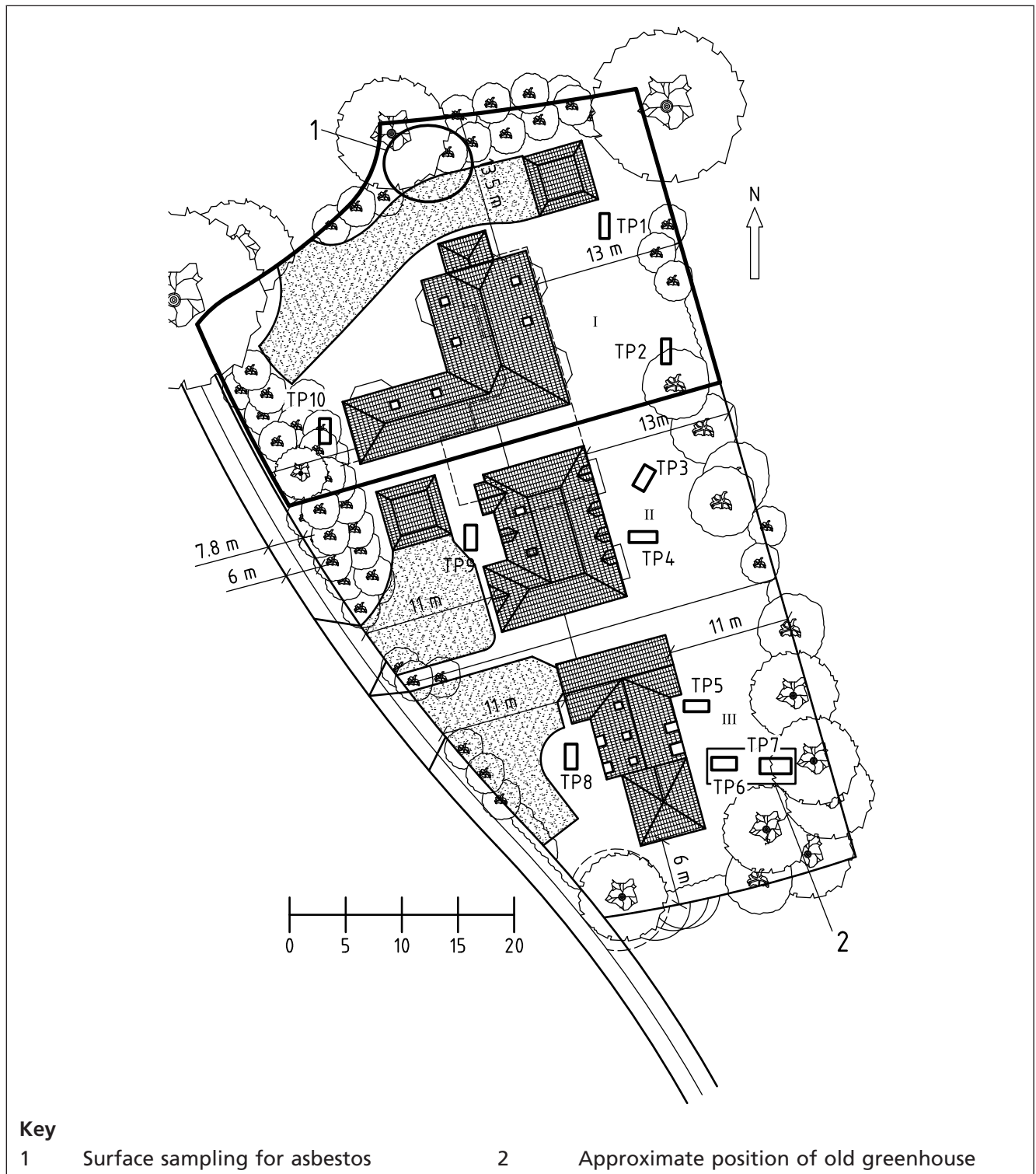


Figure G.2 Proposed layout and trial pit location plan



Annex H  
(informative)

## Photographic records

H.1

### General

Photography can be used as an investigatory tool where images of the site in a previous use are available and also as a record of the investigations carried out in terms of the condition of the site at the time and of the materials encountered within the investigation. These two different uses of photography within a ground investigation are complementary, and it is important that the investigation strategy includes obtaining a comprehensive record of the site before, during and after the investigation.

### H.2 Remote sensed images

No desk study is complete without a full review of the available remote sensed images, whether these are aerial photographs or satellite images. These images can be photographs in the visible spectrum from archives or specially flown (see Clause 14), false colour images where sensing has been made in other parts of the spectrum, or processed results from other sensors such as radar. The uses to which these different types of images can be put are summarized in Section 2.

### H.3 Site photographs

#### H.3.1 Historical photographs

An important element of the desk study is to identify any photographic records that show previous uses of the site. This is likely to be particularly important if those previous uses are potentially contaminative, they can also indicate the position of previous structures and also in case there are any indications of ground instability on the site, either due to mass movements or due to man's activities.

#### H.3.2 The site before the investigation

As part of the desk study and during the walk-over reconnaissance survey, it is essential to build a photographic record of the site and its environs including features of particular interest on and around the site. The features worth recording might include existing structures and any signs of distress, indications of mass movement, anticipated or unexplained spoil heaps, any indications of drainage such as boggy areas, any circular features.

It is useful if all photographs taken on the walk over include a date record; in addition a plan of the site showing the position and direction of the camera for each image are useful.

#### H.3.3 The site during the investigation

Photographs of the site before it is disrupted by any ground investigation activities are always useful. An additional photographic record can then usefully be compiled to show the damage to the site and the completion of restoration activities; this photographic record is useful in sorting out disputes with the contractor and the landowner.

In addition, photographs of where on the site particular investigation positions, including any monitoring installations, were constructed or tests carried out can be useful in later interpretation of findings.

It is useful if all photographs include the date and a record of where and why the picture was taken.

#### H.4 Photographs of recovered materials

A photographic record of the materials recovered during the investigation is often a contractual requirement; even if it is not, the inclusion of such a record is to be recommended. All photographs of recovered materials normally include a project reference, investigation point reference number, depth information, date, scale and colour chart.

The photographic records could include:

- looking down into trial pits at the in-situ materials;
- spoil excavated from the trial pits;
- any other exposures created in making access for plant and equipment;
- all cores recovered, whether of soil, rock or other materials;
- all samples that are split for detailed logging; and
- laboratory test specimens before and after test.

Photographs of cores are to be taken as soon as possible after extraction from the ground and before description, sampling and testing.

The following are good points to adhere to when taking photographs.

- A graduated scale running parallel to the core axis for the full length of the core box is included in photographs.
- The core fills at least 50% of the photograph frame and care is taken to ensure that the core is in sharp focus with good even lighting (this might require some form of artificial lighting).
- Cores of soil (rotary or extruded tube samples) usually show little on the outside, and so photographs can be taken once the cores have been split. Further photographs after allowing the samples to air dry might also reveal useful information on soil structure.
- In addition to routine photography of all cores and split samples, photographs are also to be taken of any atypical features.
- All photographs of the materials encountered include relevant project reference information, the number of the hole and sample, the date, an international photographic colour chart to allow correction of the colours subsequently if necessary and a scale bar.

#### H.5 Contractual requirements

The requirements for photographs to be taken during the investigation and to be included within the GIR are to be set out in the contract documents at the time of tender. These can be based on the *UK specification for ground investigation* [8], which has useful clauses to cover this activity.

## Bibliography

### Standards publications

For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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ASTM D2845-08, *Standard method for laboratory determination of pulse velocities and ultrasonic elastic constants of rock*

ASTM D2936-08, *Standard test method for direct tensile strength of intact rock core specimens*

ASTM D3967-08, *Standard test method for splitting tensile strength of intact rock core specimens*

ASTM D3999-11, *Standard test methods for the determination of the modulus and damping properties of soils using the cyclic triaxial apparatus*

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