

BS 5930:2015+A1:2020



BSI Standards Publication

Code of practice for ground investigations

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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 these committees can be obtained on request to their secretary.

Supersession

BS 5930:2015 superseded BS 5930:1999+A2:2010, which was withdrawn.

BS 5930:2015+A1:2020 supersedes BS 5930:2015, which is withdrawn.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.

BS 5930:2015 was a full revision of the standard, and introduced the following principal changes.

- The majority of changes arose 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- The revision of material that was out of date. There was 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 standard.

Text introduced or altered by Amendment No. 1 is indicated in the text by tags  . Minor editorial changes are not tagged.

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 1 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).

A1 *NOTE 2 BS 10175 is used with the BS ISO 18400 series of standards. Much of the detailed guidance in earlier versions of BS 10175 has been replaced or supplemented by reference to parts of the BS ISO 18400 series. For simplicity and to avoid repetition, all references to BS 10175 in this British Standard embrace the need to refer to applicable parts of the BS ISO 18400 series of standards as necessary.* **A1**

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: **A1** 2016 **A1**, *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*¹⁾

BS 1377-3: **A1** 2018 **A1**, *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*¹⁾

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*¹⁾

BS 1377-7:1990, *Methods of test for soils for civil engineering purposes – Part 7: Shear strength tests (total stress)*¹⁾

BS 1377-8:1990, *Methods of test for soils for civil engineering purposes – Part 8: Shear strength tests (effective stress)*¹⁾

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*

¹⁾ Partially replaced

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  +A2:2017 , *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:  2018 , *Geotechnical investigation and testing – Identification and classification of soil – Part 1: Identification and description*

BS EN ISO 14688-2:  2018 , *Geotechnical investigation and testing – Identification and classification of soil – Part 2: Principles for a classification*

 BS EN ISO 14689:2018, *Geotechnical investigation and testing – Identification, description and classification of rock* 

BS EN ISO 17892-1, *Geotechnical investigation and testing – Laboratory testing of soil – Part 1: Determination of water content*

BS EN ISO 17892-2, *Geotechnical investigation and testing – Laboratory testing of soil – Part 2: Determination of bulk density*

 BS EN ISO 17892-3, *Geotechnical investigation and testing – Laboratory testing of soil – Part 3: Determination of particle density*

BS EN ISO 17892-4, *Geotechnical investigation and testing – Laboratory testing of soil – Part 4: Determination of particle size distribution*

BS EN ISO 17892-5, *Geotechnical investigation and testing – Laboratory testing of soil – Part 5: Incremental loading oedometer test*

BS EN ISO 17892-6, *Geotechnical investigation and testing – Laboratory testing of soil – Part 6: Fall cone test*

BS EN ISO 17892-7, *Geotechnical investigation and testing – Laboratory testing of soil – Part 7: Unconfined compressive strength test*

BS EN ISO 17892-8, *Geotechnical investigation and testing – Laboratory testing of soil – Part 8: Unconsolidated undrained triaxial test*

BS EN ISO 17892-9, *Geotechnical investigation and testing – Laboratory testing of soil – Part 9: Consolidated triaxial compression tests on water saturated soils*

BS EN ISO 17892-10, *Geotechnical investigation and testing – Laboratory testing of soil – Part 10: Direct shear tests*

BS EN ISO 17892-11, *Geotechnical investigation and testing – Laboratory testing of soil – Part 11: Permeability tests*

BS EN ISO 17892-12, *Geotechnical investigation and testing – Laboratory testing of soil – Part 12: Determination of liquid limit and plastic limit*

BS EN ISO 18674-2, *Geotechnical investigation and testing – Geotechnical monitoring by field instrumentation – Part 2: Measurement of displacements along a line: Extensometers*

BS EN ISO 18674-3, *Geotechnical investigation and testing – Geotechnical monitoring by field instrumentation – Part 3: Measurement of displacements along a line: Inclinometers*

BS EN ISO 18674-4, *Geotechnical investigation and testing – Geotechnical monitoring by field instrumentation – Part 4: Measurement of pore water pressure: Piezometers* ^(A1)

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: Infiltrometer 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: ^(A1) 2020 ^(A1), *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*

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*

BS EN ISO 22476-9, *Geotechnical investigation and testing – Field testing – Part 9: Field vane test*²⁾

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*

²⁾ In preparation.

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.

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+A2:2017, 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, cemented or otherwise bonded together, so as to form material of generally greater strength or stiffness than soils

Ⓐ [SOURCE: BS EN ISO 14689:2018, 3.5, modified] Ⓐ

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.

3.15 discontinuity

break in the soil or rock material continuity that is open or can open under the stress increase or reduction as a result of engineering works

[SOURCE: BS EN ISO 14689:2018, 3.1]

3.16 soil or rock mass

soil or rock comprising the intact material together with the discontinuities and weathering zones

[SOURCE: BS EN ISO 14689:2018, 3.6, modified]

3.17 soil or rock material

intact soil or rock between the discontinuities

[SOURCE: BS EN ISO 14689:2018, 3.7, modified] 

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 formulated 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 **A1** (see Parry et al., 2014 [0]).

Ground models should progress from a basic description or diagram of ground conditions to a two-dimensional textual or graphic description to a three-dimensional model to a multi-disciplinary information model as appropriate. **A1** The model should be continually 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. ^[A] The Association of Geotechnical and Geoenvironmental Specialists (AGS) and the British Drilling Association (BDA) have produced a range of health and safety guidance documents available for download at www.ags.org.uk and www.britishdrillingassociation.co.uk respectively. ^[A1]

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 18400-103  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 can present toxicological risks of varying severity. Methane, hydrogen sulfide and some volatile organic compounds (VOCs) can form explosive mixtures with air. (For further information and guidance, see www.safetydirectory.com/hazardous_substances/hydrogen_sulfide/fact_sheet.htm [last viewed 24 June 2015].) 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. See www.coal.decc.gov.uk [last viewed 24 June 2015].

A1 5.3 Asbestos

COMMENTARY ON 5.3

The presence of loose asbestos fibres and/or asbestos-containing materials (e.g. asbestos insulation or fragments of insulating board, 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.

All work activities that could potentially disturb asbestos on or in the ground fall under the requirements of the Control of Asbestos Regulations 2012 (CAR2012) [158], as well as the accompanying HSE Approved Code of Practice L143 [5a]. In 2016, CL:AIRE published guidance on the interpretation of CAR2012 [158] and L143 [5a] for all work activities that might disturb asbestos in the ground – CAR-SOIL [5b].

For further guidance, see BS 10175:2011+A2:2018, 7.3.2.

The possible presence of asbestos and asbestos-containing materials should be taken into account in any disturbance of the ground.

The potential presence of asbestos should be taken into account during the preliminary risk assessment at all sites unless adequate justification for not doing so can be documented (see CIRIA Report C765 [5c]).

Contingency plans should always be in place so that investigation personnel know how safely to proceed if asbestos is unexpectedly encountered in the ground (see AGS guidance [4]).

When engaging in ground investigation activities that potentially could or are likely to disturb asbestos, employees should be provided with sufficient information, instructions and training to be safe.

Made ground can often contain asbestos, so site operatives should have as a minimum asbestos awareness training. Where sampling of known or suspected asbestos is required, the site operative should have non-licensed work, as well as asbestos awareness, training.

NOTE 1 Attention is drawn to Regulation 10 of CAR2012 [158], which includes requirements on training, and to CAR-SOIL [5b].

NOTE 2 The risk to human health from asbestos arises from the inhalation of asbestos fibres that become airborne when the soil that contains them is disturbed, or when asbestos-containing material in the soil is broken or abraded. The magnitude of the risk depends on the probability of this happening. This depends on such factors as whether the fibres are bound firmly in a matrix, the activity that causes disturbance of the soil (e.g. excavation, construction works, gardening), the nature and condition of the soil (e.g. whether it is wet), and weather conditions (e.g. wind). Provided that the soil is not disturbed, then whilst there might be a significant hazard present, the actual risks might be insignificant. The main considerations then become whether there might be disturbance in the future and whether this can be guarded against.

*NOTE 3 There has been considerable effort in recent years by industry in conjunction with the HSE to produce guidance on how to assess and deal with asbestos in the ground. See, for example, AGS guidance [4], CIRIA Report C733 [5d], CIRIA Report C765 [5c] and SOBRA guidance [5e]. **A1***

5.4 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].

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.

NOTE 1 *Laboratories are only accredited by individual test method. See the Foreword for guidance on test laboratory accreditation.* 

NOTE 2 *It is desirable that the laboratory participates in external proficiency testing schemes, as available, relevant to the work being commissioned; see the AGS website, www.ags.org.uk [last viewed 24 June 2015].*

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.

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 archaeological, 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

A1 A ground model should be formed and developed (see Clause 4). A desk study and field reconnaissance should be carried out to inform a ground investigation programme **A1** 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 **A1** three-dimensional **A1** 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, **A1** BS ISO 18400-202 and BS ISO 18400-205 give **A1** 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.*

A1 *NOTE 5 For contamination-related (geoenvironmental) investigations reference is made to the "conceptual site model", sometimes "initial conceptual site model". This is equivalent to the geotechnical ground model, and will have many features in common. The conceptual site model is similarly updated as the investigation and the overall project proceeds. Guidance on the development of the conceptual site model is provided in BS 10175 and BS EN ISO 21365 (in preparation). **A1***

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 6 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 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].

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).

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 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 soil 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.³⁾ 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.

³⁾ 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 [last viewed 24 June 2015].

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).

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 ^(A1) including ecosystem services ^(A1) 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, such as ground displacement maps from interferometry (e.g. InSAR [Interferometric Synthetic Aperture Radar]) can also provide practical information on ground conditions. ^{A1} Historical imagery might be used to prove a baseline (see also 13.6). ^{A1}

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 (RPVs), 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).

^{A1} The scale of photography used should be relevant to the investigation under consideration. ^{A1}

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 RPVs 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.

^{A1} *NOTE 4 The majority of pre-1980s archive air photography is monochrome. True colour 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 use 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 5 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 6 High resolution satellite imagery can be used for acquiring base imagery (orthoimagery) and for DEM generation.

NOTE 7 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 8 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 – Pan-European Ground Motion Hazard Information Service (www.terrafirma.eu.com/TerraFirma [last viewed 24 June 2015]).

NOTE 9 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 10 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. ^(A1)

14.3 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.

^(A1) Text deleted ^(A1)

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 A_1 or harmful chemical or biological agents (pathogens), A_1 therefore requiring special controls on excavation, movement, A_1 treatment on site, A_1 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 A_1 soil A_1 and a reduction of bearing capacity of permeable A_1 soil, A_1 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 soil 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 [A1](#) BS ISO 18400-102 [A1](#)).

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 archaeological 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 **7.7.2** **A1**) 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 [A1](#) BS ISO 18400-103 [A1](#) and CIRIA R132 [1]. Where asbestos might occur, [A1](#) more specific guidance is given in 5.3. [A1](#)

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 [A1](#) and BS ISO 18400-105 [A1](#)).

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 (see www.brebookshop.com for recent publications [last viewed 24 June 2015]).

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, $\mathbb{A}_1$ dimensions and masses (see BS 1377-1) $\mathbb{A}_1$ is such as to permit an appropriate programme of laboratory testing 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).

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 $\mathbb{A}_1$ carry out field testing (such as probing or CPT) and/or to $\mathbb{A}_1$ 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

A1 BS EN ISO 22475-1:2020, Table 4 and Annex D. **A1**

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, **A1** masses and dimensions **A1** 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, **A1** including borehole or pit and depth, required and test conditions, if needed, **A1** 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 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.

A1 *NOTE 3 Guidance on the management of Japanese knotweed on development sites has been provided by documents from the Invasive Non-Native Specialists Association (INNSA) [20a] and the Property Care Association (PCA) [20b]. This industry guidance replaces that formerly provided by the Environment Agency. Background information on invasive and injurious species can be found at: www.gov.uk/guidance/prevent-the-spread-of-harmful-invasive-and-non-native-plants [last viewed 18 March 2020]. **A1***

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 A_1 (see 25.2). The five sample quality classes, together with sampling categories to which they are linked, are defined in BS EN ISO 22475-1:2020, Table 1 and Table 2 for soil and for rock respectively. A_1 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. A_1 Text deleted A_1 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.

A_1 For more detailed information on the applicability of the various drilling and sampling techniques, reference should be made to BS EN ISO 22475-1. A_1

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 A_1 primary A_1 or secondary fractions, can present significant difficulties to drilling and sampling. The largest particles can obstruct the drilling process A_1 Text deleted A_1 , often being the obstacle to any further progress. A_1 They might