

BS 6031:2009

Incorporating Corrigendum No. 1



BSI Standards Publication

Code of practice for earthworks

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Contents

Foreword *iii*

Section 1: General 1

Introduction 1

- 1 Scope 3
- 2 Normative references 3
- 3 Terms and definitions 5
- 4 The control of risk 10

Section 2: Design and management of earthworks 13

- 5 Planning of earthworks 13
- 6 Site conditions and investigations 17
- 7 Design of earthworks 27
- 8 Specification of earthworks fill materials 70
- 9 Construction of earthworks 78
- 10 Adoption 88
- 11 Earthworks asset management 91
- 12 Decommissioning and disposal of earthworks assets 99

Section 3: Temporary excavations, trenches, pits and shafts 100

- 13 Temporary excavations 100
- 14 Construction procedure 106
- 15 Trenches 107
- 16 Pits and shafts 110

Annexes

Annex A (informative) Potential modes of failure of slopes 111

Bibliography 115

List of figures

- Figure 1 – Flow diagram of lifecycle of an earthworks project 3
- Figure 2 – The iterative feedback processes of a site investigation 23
- Figure 3 – Example of possible surcharge combination on a slope 31
- Figure 4 – General procedure for determining characteristic values from measured values 33
- Figure 5 – Variations of ϕ' with displacement 35
- Figure 6 – Variation of ϕ' , ϕ'_r with I_p 36
- Figure 7 – Short and long term stability of embankment and cutting slopes 38
- Figure 8 – Design of earthworks drainage to capture significant flows 50
- Figure 9 – Determination of acceptability limits for coarse soils using relationship testing data 61
- Figure 10 – Determination of acceptability limits for fine soils using relationship testing data 61
- Figure 11 – Example of relationship testing 62

List of tables

- Table 1a) – Soil classification (after BS EN ISO 14688-1:2002) 7
- Table 1b) – Grouping of soils for testing purposes (after BS 1377-1) 7
- Table 1c) – Comparison of soil definitions in different earthworks circumstances 8
- Table 2 – Indicative earthworks tests by test type and material type 20
- Table 3 – Nominal load due to live surcharge 31
- Table 4 – Partial factors on actions or the effects of actions 41
- Table 5 – Partial factors for soil parameters 42
- Table 6 – Partial resistance factors for slopes and overall stability 42
- Table 7 – Typical characteristics of foundation and embankment fill materials 54

Table 8 – Classification of earthworks materials in the UK by the Highways Agency	73
Table 9 – Example of classification and acceptability testing table	74
Table 10 – Classification and acceptability tests	75
Table 11 – Relevant sections of CIRIA C591 and C592	92
Table A.1 – Definitions of potential modes of failure of slopes	111

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 120, an inside back cover and a back cover.

Foreword

Publishing information

This British Standard is published by BSI and came into effect on 31 December 2009. It was prepared by Technical Committee B/526, *Geotechnics*. A list of organizations represented on this committee can be obtained on request to its secretary.

Information about this document

The start and finish of text introduced or altered by Corrigendum No. 1 is indicated in the text by tags C1 C1.

Supersession

This British Standard supersedes BS 6031:1981, which is obsolescent.

NOTE It was considered important to make the information on timber support and other largely historic advice available through the previous edition, which is still available from BSI.

Relationship with other publications

The standard has been completely re-written to bring it into line with both UK earthworks practice and the framework that is created by the Eurocodes. The aim was to reduce the size of the document and wherever possible include cross references to other existing documents.

This revision of BS 6031 reflects the widespread UK practice of using the Specification for Highway Works (SHW) 600 series [1] for the construction of earthworks. Within this standard, the SHW has been set as the default approach for earthworks specification that applies unless the designer details an alternative form of specification/earthworks management system.

Cross references are included within this standard to various other documents, to link into the existing information sources available. However, it remains the responsibility of the designer of the earthworks for a project to assess whether a reference is relevant to the particular project.

Use of this document

As a code of practice, this 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 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 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 in 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.

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.

Section 1: General

Introduction

The structure for this document reflects the actual processes that might be followed on a typical project to deliver the earthworks. In practice earthworks design is an iterative process where design decisions are often taken by various parties (employer, consultant, main contractor, sub-contractors and construction validation team). To reflect this situation BS 6031:2009 includes some subjects in more than one clause.

This revision of BS 6031 reflects the widespread UK practice of using the Specification for Highway Works (SHW) 600 series [1] for the construction of earthworks. Within this standard, the SHW has been set as the default approach for earthworks specification that applies unless the designer details an alternative form of specification/earthworks management system. Guidance on the use of the SHW can be found in *Notes for Guidance to the Specification for Highway Works* [2].

Earthworks are commonly associated with transport infrastructure, but there are many other important applications:

- platforms for industrial, commercial and residential buildings;
- water engineering, flood defence and coastal protection works;
- other civil engineering projects.

BS 6031 is intended to be an all-encompassing code of practice; the document has been developed to enable it to cover all earthworks projects, with the exception of dams. In this regard it is relevant to note the following.

- a) Embankment dams are constructed either to retain water or for waste impoundments and, while some aspects of the design, construction and maintenance of such embankments are similar to those pertaining to infrastructure embankments, those features which relate specifically to their function as dams are not within the scope of this standard. Note that since 1930 reservoir safety in Great Britain has been regulated by Act of Parliament. *A guide to the Reservoirs Act 1975*¹⁾ [3] describes the application of current legislation and *An engineering guide to the safety of embankment dams in the United Kingdom* [4] provides some relevant information on earthworks.
- b) Substantial earthworks can take place for the purpose of providing a suitable landform for building development. Typically this can involve:
 - 1) backfilling old pits and quarries with engineered fill;
 - 2) cut and fill operations on natural slopes to provide terraces for building.

In the former situation the major hazard to be guarded against is long-term settlement of the fill occurring subsequent to building development; in the latter situation slope instability can also be a significant hazard. While most of the technical background

¹⁾ Likely to be revised in 2010.

of highway earthworks (as captured within the SHW [1]) is also relevant to this type of application, two significant differences have to be recognized where structures are built on fill:

- i) settlement criteria can be much stricter than those normally acceptable for general earthworks; the designer has to consider whether the SHW [1] criteria are sufficient for the project; and
- ii) the engineering environment in which the earthworks are carried out does influence the approach that is applicable to earthworks; this is particularly relevant on comparatively small scale projects where the designer might need to modify the approach to earthworks.

This standard has been drafted to include sufficient flexibility to allow for these scenarios.

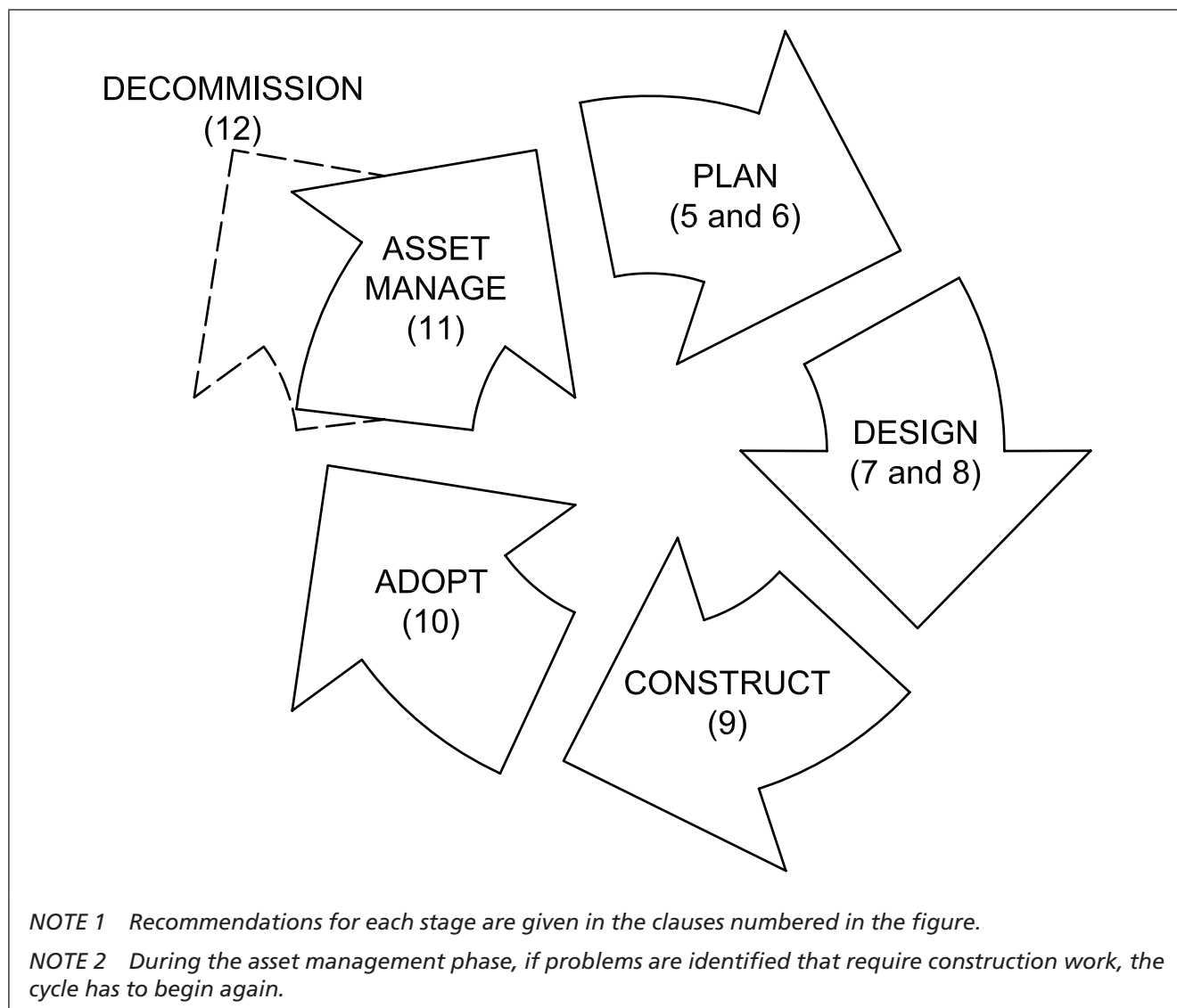
This standard is aligned with Eurocode BS EN 1997-1:2004. Advice on using BS EN 1997-1:2004 is provided in Thomas Telford *Designers' Guide to EN 1997-1 Eurocode 7: Geotechnical Design – General Rules* [5], local government guide *A designer's simple guide to BS EN 1997* [6], and CIRIA C641, *Eurocode 7: implications for UK practice* [7]. These publications help highlight differences between BS EN 1997-1:2004 and previous traditional practice.

The foreword to BS EN 1997-1:2004 states that “BS 6031 is to be withdrawn”, which is an error; it has been agreed since the publication of BS EN 1997-1:2004 that BS 6031 will remain as part of the system of earthworks standards in UK.

The style adopted within BS 6031:2009 is to cross reference BS EN 1997-1:2004 (not repeat it), summarize the aspects of BS EN 1997-1:2004 that form the overall framework for undertaking an earthworks project, include an interpretation of certain key points that are relevant/important to earthworks (e.g. selection of partial factors to be used at design stage) and add additional information that is relevant to earthworks (i.e. add some commentary to the “dry rules” set out in BS EN 1997-1:2004). The overall aim is for BS 6031 to be non-conflicting complementary information (NCCI) to BS EN 1997-1:2004.

This edition of BS 6031 is set out in clauses to reflect the overall earthworks process: where earthworks are planned, designed, constructed, adopted/approved following construction, and then the earthworks moves into an asset management process. This cycle is only broken when the earthworks reach the end of their useful life and are decommissioned. This cycle is illustrated in Figure 1. This standard recognizes that construction of new earthworks and the remediation or repair of existing earthworks are activities that have similarities and significant differences. Wherever possible, clauses cover both construction and remediation activities, which need to be taken into consideration as appropriate.

Figure 1 Flow diagram of lifecycle of an earthworks project



1 Scope

This standard gives recommendations and guidance for unreinforced earthworks forming part of general civil engineering construction, with the exception of dams. This standard also gives recommendations and guidance for temporary excavations such as trenches and pits.

NOTE Reinforced earthworks are covered in BS 8006-1 and BS 8006-2.

This document applies to earthworks classified as Geotechnical Category 1, 2 and 3 structures as defined in BS EN 1997-1:2004.

2 Normative references

Standards publications

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

BS 812-109, *Testing aggregates – Methods for determination of moisture content*

BS 1377 (all parts), *Methods of test for soils for civil engineering purposes*²⁾

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

BS 1924-2, *Stabilized materials for civil engineering purposes – Part 2: Methods of test for cement-stabilized and lime-stabilized materials*

BS 5607, *Code of practice for the safe use of explosives in the construction industry*

BS 5930:1999+A1:2007, *Code of practice for site investigations*³⁾

BS 6164, *Code of practice for safety in tunnelling in the construction industry*

BS EN 474 (all parts), *Earth-moving machinery – Safety*

BS EN 500-4, *Mobile road construction machinery – Safety – Part 4: Specific requirements for compaction machines*

BS EN 791, *Drill rigs – Safety*

BS EN 1990:2002+A1:2005, *Eurocode 0 – Basis of structural design*

BS EN 1997-1:2004, *Eurocode 7: Geotechnical design – Part 1: General rules*⁴⁾

BS EN 1997-2:2007, *Eurocode 7: Geotechnical design – Part 2: Ground investigation and testing*⁵⁾

BS EN 1998-5, *Eurocode 8: Design of structures for earthquake resistance – Part 5: Foundations, retaining structures and geotechnical aspects*

BS EN 12111, *Tunnelling machines – Road headers, continuous miners and impact rippers – Safety requirements*

BS EN 13331-1, *Trench lining systems – Part 1: Product specifications*

BS EN ISO 14688-1:2002, *Geotechnical investigation and testing – Identification and classification of soils – Part 1: Identification & description*

BS EN ISO 14688-2:2004, *Geotechnical investigation and testing – Identification and classification of soils – Part 2: Classification principles*

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

NA to BS EN 1990:2002+A1:2005, *UK National Annex for Eurocode – Basis of structural design*

²⁾ Under revision to act as NCCI to BS EN 1997-2:2007.

³⁾ Under revision with the intention that BS 5930 remains as the “first stop” for site investigations but also to act as NCCI to BS EN 1997-2:2007.

⁴⁾ Any general reference to BS EN 1997-1:2004 is also to be taken as a reference to NA to BS EN 1997-1:2004.

⁵⁾ Any general reference to BS EN 1997-2:2007 is also to be taken as a reference to NA to BS EN 1997-2:2007.

NA to BS EN 1997-1:2004, *UK National Annex to Eurocode 7 – Geotechnical design – Part 1: General rules*

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

Other normative references

- [1] *Manual of Contract Documents for Highway Works, Volume 1 – Specification for Highway Works, Series 600 – Earthworks*. Highways Agency. (www.standardsforhighways.co.uk)

3 Terms and definitions

3.1 General

For the purposes of this British Standard, the definitions given in Table 1a), Table 1b), Table 1c), 3.2 and 3.3 apply, together with those given in BS 1377-1, BS EN 1997-1:2004 and BS EN 1997-2:2007.

Within the Eurocode family of documents, BS EN ISO 14688-1:2002 and BS EN ISO 14688-2:2004 establish the basic principles for the identification and classification of soils for engineering purposes. Identification and description of a soil is initially undertaken on the basis of visual techniques in accordance with BS EN ISO 14688-1:2002. BS EN 1997-2:2007, Table 2.1 states that the main soil groups are according to BS EN ISO 14688-1:2002 which defines soils as being:

- Made Ground;
- organic soil;
- volcanic soil;
- fine soils [see Table 1a)];
- coarse soil [see Table 1a)]; or
- very coarse soil [see Table 1a)].

BS EN ISO 14688-1:2002, Figure 1 is a “flow chart for the identification and description of soils” for general (preliminary) characterization of soils after the very coarse fraction (cobbles and boulders) has been screened out. A general test is used to classify the soil type on the basis of “does the soil stick together when wet?”

- Yes (i.e. particles stick together) then = fine soil.
- No (i.e. particles don’t stick together) then = coarse soil.

Basic soils are defined as soils with uniform grading that consist of particles of only one size range, the definition of particle names and particle size ranges are set out at Table 1 of BS EN ISO 14688-1:2002, which are illustrated in Table 1a).

In reality almost all uniformly graded soils have some proportion of other particle sizes. The Eurocode system does not set an upper bound on the proportion of secondary fraction required before a soil is defined as a composite soil; this is likely to depend on the soil type. However, in earthworks less than 10% of secondary fraction might be considered as a general guide below which the soil could be considered as a basic soil (rather than a composite soil). The most likely exception would be sand where a fines content of less than 10% can significantly influence the engineering behaviour in earthworks and in that case would be considered a composite soil.

BS EN ISO 14688-2:2004 provides the principles for a more detailed classification of a soil where laboratory test data are available to allow grading, plasticity and organic content to be taken into account more fully. With regard to grading, BS EN ISO 14688-2:2004, Table 2 sets criteria for the designation of coarse fractions based on the shape of the grading curve (both uniformity coefficient and coefficient of curvature C_c). In earthworks particular consideration should be given to the uniformity coefficient (C_u , previously designated U_c , defined as particle size at which 60% of the material is finer/particle size at which 10% is finer). Soils that have a uniformity coefficient of less than 6 (and $C_c < 1$) are distinctly uniform in grading and described as “evenly-graded”. The phrase “uniformly graded” is a general descriptive term in BS EN ISO 14688-2:2004 (unlike “evenly-graded”), but, the SHW [1] system sets a uniformity coefficient upper limit of 10 for classification of uniformly graded granular material which remains a valid consideration for earthworks.

The grouping of soils by particle size for testing purposes [see Table 1b)] is significantly different to that used for soil particle size classification [see Table 1a)]. BS 1377-1 divides soil groups based on the soil sizes that are suitable for different forms of test.

Most soils consist of a principal and secondary fractions and are defined as “composite soil”, the identification of which is described at BS EN ISO 14688-1:2002, 4.3. A composite fine soil is one where the fines fraction determines the engineering properties of the soil (this can include relatively coarse soil where the fine matrix is sufficient to result in the soil being matrix dominated); where the fines fraction is insufficient to determine the engineering properties the soil is a composite coarse soil. To fully classify the soil consideration is given to other factors including plasticity of the fines fraction (test carried out on $< 425 \mu\text{m}$ material). However, the principles for classification of soils set out at BS EN ISO 14688-2:2004 is useful in assessing likely earthworks behaviour.

In the field of earthworks the assessment of whether the fines fraction (i.e. passing a $63 \mu\text{m}$ sieve) is sufficient to determine the engineering properties of the soil will differ between two major cases:

- where a soil is considered as an engineered fill, where all fills with $> 15\%$ fines are classified as cohesive; and
- soil assessed for geotechnical design (e.g. slope stability, settlement or bearing capacity) where generally fine (cohesive) soils are likely to include $> 35\%$ fines.

Therefore, in accordance with industry practice, the soils described in this standard as “coarse/granular”, “intermediate” or “fine/cohesive” contain different percentages of fines depending on the context in which the descriptions are used [see Table 1c)]. Table 1c) also provides a simplified summary of the BS EN ISO 14688-1:2002 approach to illustrate that both approaches fit within that framework.

In composite soils the assessment of the “dominant soil fraction” which will determine the engineering properties of the soil requires consideration of a variety of soil characteristics (particularly plasticity, grading and soil fabric). Within the intermediate zones illustrated in Table 1c) experience shows that seemingly similar soils can behave differently with relatively small differences in these soil characteristics. These variations are very notable in glacial till as described in CIRIA C504 [8].

Note that Table 1a) and Table 1b) are presented based on particle sizes, while Table 1c) shows percentage passing the $63 \mu\text{m}$ sieve.

Table 1a) Soil classification (after BS EN ISO 14688-1:2002)

Particle Sizes mm	0.002	0.0063	0.02	0.063	0.2	0.63	2.0	6.3	20	37.5	63	200	630	>630
Soil fraction	Fine soil			Coarse soil					Very coarse soil					
Sub-fraction	Clay	Silt		Sand		Gravel			Cobble	Boulder	Large Boulder			
		Fine	Medium	Coarse	Fine	Medium	Coarse	Coarse						

Table 1b) Grouping of soils for testing purposes (after BS 1377-1)

Soil Group	Fine-grained soil ^{A)}				Medium-grained soil ^{B)}			Coarse-grained soils ^{C)}	Soil too coarse to be covered by BS 1377 ^{D)} (Zone X Material)		

A) Soils containing not more than 10% retained on a 2 mm test sieve.

B) Soils containing more than 10% retained on a 2 mm test sieve but not more than 10% retained on a 20 mm test sieve.

C) Soils containing more than 10% retained on a 20 mm test sieve but not more than 10% retained on a 37.5 mm test sieve.

D) Soils with more than 10% of material retained on a 37.5 mm test sieve are not covered by the laboratory tests detailed in BS 1377-1: except for particle size analysis, and the moisture content and plasticity tests of the finer fraction if present. However, for earthworks control purposes the designer may still choose to utilize the test methods on a modified sample in order to generate test data to consider potential performance (see 7.6.4).

Table 1c) Comparison of soil definitions in different earthworks circumstances

% passing a 63 µm sieve		0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
UK standard approach to earthworks material classification by grading (after SHW ^{A),B)})	fill behaviour	granular fill		intermediate fill ^{C)} , classified as cohesive fill																		
UK traditional approach to classification for geotechnical design (after BS 5930:1999+A1 ^{D)})	soil parameters	coarse/granular		intermediate zone ^{C)}																		
BS EN 1997-1:2004 geotechnical design approach, (after BS EN ISO 14688-1:2002 ^{E)})	simplified interpretation for comparison purposes	coarse soil		composite coarse soil																		
				BS EN 1997-1:2004 approach does not set any fixed boundary but generally > 10% of the secondary fraction is likely to be needed in most soil types to constitute a composite soil.																		

A) SHW [1] sets the granular/intermediate divide at 15% in recognition of pore water pressure in dynamic action of compaction.

B) The terms "granular" and "cohesive" are included here with regard to behaviour, the soil description terms in accordance with BS 5930:1999+A1 are "coarse" and "fine".

C) The designer has to use judgement of how a soil will behave within the intermediate zone, which is not considered in BS 5930:1999+A1.

D) Most fills in the UK that are in the intermediate range are classified as class 2C. Alternatively, the designer can create a new site-specific class e.g. "class 2F, clayey sand".

E) The BS EN 1997-2:2007 approach for identification and description of soils is set out within BS EN ISO 14688-1:2002, 4.3, by this system many soils are classified as composite soils and the distinction between soil terms can be summarized as follows:

- "composite fine soil" is a soil where the fines content is sufficient to determine the engineering properties;
- "composite coarse soil" is a soil where the fines content is not sufficient to determine the engineering properties (BS EN ISO 14688-1:2002 should be referred to for the full determination procedures).

3.2 Terms used in Section 2

3.2.1 berm

relatively narrow bench or shelf which is provided to break the continuity of a long slope, or as a trap to contain loose material rolling down a slope

3.2.2 colluvial deposits

weathered material transported by gravity, e.g. scree, talus, and landslip debris

3.2.3 earthwork

work of excavating, or the raising or sloping of ground

NOTE 1 From BS 6100-1:2004.

NOTE 2 The work can be a stand-alone activity or part of a larger project.

3.2.4 earthworks

- 1) structures formed by the excavating, raising or sloping of ground, e.g. embankments, cuttings or remediated natural slopes
- 2) civil engineering process that includes extraction, loading, transport, transformation/improvement, placement and compaction of natural materials (soils, rocks), and/or secondary or recycled materials, in order to obtain stable and durable cuttings, embankments or engineered fills

3.2.5 landslip landslide

readily perceptible down-slope movement of a soil or rock mass, occurring primarily through shear failure on discrete surfaces at the boundaries of the moving mass

3.2.6 piezometer

open or closed tube or other device installed downward from the ground surface and used to measure the ground water pressure in the region where the piezometer tip is situated

3.2.7 scree

accumulated rock debris at the foot of a cliff

NOTE See colluvial deposits.

3.2.8 slope face angle

angle of any slope expressed either in degrees to the horizontal or as the tangent of the angle to the horizontal (e.g. a slope of 1 in 3 makes an angle to the horizontal whose tangent is 1/3, i.e., 18.5°)

3.2.9 solifluction

slow downhill movement of soil or scree cover as a result of the alternate freezing and thawing of the contained water

3.2.10 spoil

soil, rock or other excavated material which is not required for filling in embankments or as backfill of excavations, and is surplus material removed from the site

3.2.11 subsidence

downward movement, predominantly vertical in direction, due to removal, consolidation, or displacement of the underlying strata

3.3 Terms used in Section 3

3.3.1 trench

excavation whose length greatly exceeds its width

3.3.2 shallow trench

trench up to 1.5 m in depth

3.3.3 medium trench

trench between 1.5 m and 6.0 m in depth

3.3.4 deep trench

trench exceeding 6.0 m in depth

3.3.5 narrow trenches

class of excavation too narrow to allow the entry of personnel

3.3.6 pit

excavation ranging from that required to receive the foundation base for a pier or column to that required to receive the basement and foundations of a building, including trial pits excavated for site investigation purposes

3.3.7 shallow pit

pit up to 1.5 m in depth

3.3.8 medium pit

pit between 1.5 m and 6.0 m in depth

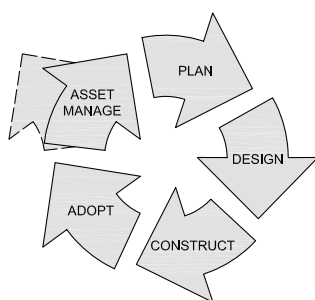
3.3.9 deep pit

pit exceeding 6.0 m in depth

3.3.10 shaft

excavation, which may be either vertical or inclined, constructed to give access to underground works

NOTE Shallow, medium and deep shafts are defined in the same way as shallow, medium and deep pits.



4 The control of risk

4.1 Competence

For earthworks to be successfully designed, constructed and maintained, it is important that the personnel undertaking each task should be competent. When possible this should be managed by the implementation of a system to demonstrate the competence of the staff involved.

In some industries there are specific requirements for competence management systems which should be adhered to, e.g. *Railway safety principles and guidance* [9].

4.2 Risk management

4.2.1 Projects

The management of risk should be a key aspect of projects involving earthworks as in all construction activity. The areas of risk to be managed should include:

- programme, quality and financial risks to ensure the successful delivery of the project;
- health and safety, along with environmental risks to satisfy statutory requirements.

NOTE 1 All projects involving earthworks come under the requirements of the Construction (Design and Management) Regulations 2007 [10] (CDM).

All those involved in design (and construction) activities associated with earthworks should consider the requirements of the project and seek to follow the “spirit of CDM” to ensure the approach taken is appropriate for the project.

NOTE 2 BS EN 1997 (both parts) [C1] was not drafted to follow the UK’s CDM regulations, however it is consistent with the spirit of CDM. [C1]

NOTE 3 The creation and maintenance of a project risk register (PRR) is seen as good practice and is a requirement under CDM [10].

All risks identified by those involved in the design of earthworks should be fed into the PRR. It is important to realise that various parties have an input to the design of earthworks, and therefore as designers they should engage with development of the PRR.

Where a project includes geotechnical design, a geotechnical risk register (GRR) should be developed to support and enhance the PRR. The scale of the GRR depends on the complexity of the project. This approach should help the earthworks team manage out or minimize some of the geotechnical risks; all residual risks should then be fed into the PRR. On projects with multiple design teams, risks should be highlighted and their management co-ordinated in the PRR.

A GRR will tend to divide into two distinct sections:

- a) the “risks affecting investigation”, which relate to the procurement and implementation of the site investigation (e.g. access, buried services, contamination, topography); and
- b) the “risk affecting works” which relate to prevailing geotechnical conditions that might affect the design and construction of the project.

For further details see Section 2, *Design and management of earthworks*.

4.2.2 Asset management

Maintenance of existing earthworks should follow the management approach of reducing risk levels to “as low as reasonably practicable” (ALARP), giving consideration to whether spending on remedial works will result in a cost benefit over a realistic maintenance period. Remedial works become a self-contained project requiring design and construction with concomitant geotechnical risks that should be approached as described in 4.2.1.

4.3 Geotechnical certification

The concept of staged approval of a scheme via a certification system is of benefit to the control of risk, and should be adopted on complex projects involving earthworks (BS EN 1997-1:2004, Geotechnical Category 2 and Geotechnical Category 3). The geotechnical certification scheme should be flexible enough to enable the level of detail required to be appropriate for the complexity and scale of the

project. When used, geotechnical certification can be a very effective system to record the identification and management of risks by the geotechnical design team.

BS EN 1997-1:2004 does not require certification but BS EN 1997-1:2004, Section 4 does require the designer to specify requirements for inspection and testing during construction, which for earthworks might be most easily achieved by a form of certification.

NOTE One system is that operated by the Highways Agency (see HD 22/08 [11]), which embraces the requirements of BS EN 1997-1:2004, Section 4.

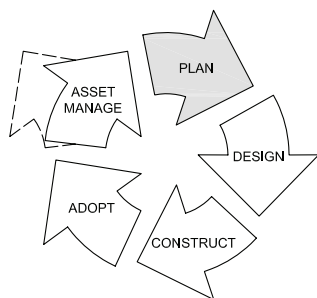
4.4 Geotechnical feedback report

Construction Design and Management Regulations [10] require the drafting of a health and safety file that contains full records of the works constructed. As-built records have to include details of the earthworks undertaken for a project to assist with future maintenance, design of additional works or decommissioning of the works.

For earthworks projects, the as-built records can be significantly enhanced by the inclusion of a geotechnical feedback report (GFR) that includes details of the earthworks undertaken. All parties involved have to be aware of the need to capture records of the works undertaken from an early stage of the project. This approach can bring significant benefits in the management of risk. When prepared, this document becomes one element of the health and safety file. The relationship between the GFR and other documentation is illustrated in 6.5.

BS EN 1997-1:2004 does not specifically include the concept of the GFR, however BS EN 1997-1:2004, Section 4 covers many of the topics which need to be addressed within this style of report. The GFR is considered an appropriate way of recording the data from earthworks projects to form a complementary record to the as-built drawings and meet the requirements of BS EN 1997 (both parts).

Section 2: Design and management of earthworks



5 Planning of earthworks

5.1 Introduction

Clause 5 is provided as a brief summary of some of the issues that should be considered when planning an earthworks project; it is not intended to be a complete list and is provided only as guidance. The person applying the code should remain cognisant of the current and applicable statutory requirements that apply to all civil engineering projects.

5.2 Sustainable development

Earthworks should be designed with sustainability in mind. For the purpose of this standard sustainable development is taken to mean: “an enduring, balanced approach to economic activity, environmental responsibility and social progress” (BS 8900:2006).

COMMENTARY ON 5.2

In future projects, evaluation of options will increasingly be required to consider construction cost and whole life cost, but also include an evaluation of the “carbon footprint” of various scheme options. The designer will be expected to calculate the “embodied carbon” present in various designs (this requires consideration of all aspects of an earthwork solution, e.g. import/export of fill materials; plant operations; use of carbon-based geosynthetic materials; soil modification or stabilization, etc.).

This process is intended to prioritize “carbon critical design”. To encourage designers to follow this approach, both the Environment Agency (EA) and Highways Agency websites provide “carbon calculators” (based on research undertaken by Bath University) that are suitable for undertaking a basic assessment of earthwork scheme options. It is likely that these calculators will be progressively enhanced as experience is developed in this field.

5.3 Scheme conception

5.3.1 Design strategy

The earthworks team should aim to provide an earthworks design that is feasible, functional, constructible and suitable for the proposed end use. Consideration should be given to land requirements, including all temporary works. The design should be developed to minimize environmental impact during the construction phase, in use and for future maintenance operations.

5.3.2 Consultations

5.3.2.1 General

The consultation process is a necessary part of any earthworks design and should be implemented at an early point following the project’s conception.

The earthworks team should identify their environmental, legal and planning obligations at the earliest opportunity to enable them to conceive and develop the project in the most effective way.

The nature of the consultation(s) will depend on the size of the project, and should involve dialogue with both regulatory and community bodies.

5.3.2.2 Regulators

It is important to develop a constructive dialogue with the regulators to ensure that they are aware of what is happening on the project and the reasons behind any design decisions that are made.

COMMENTARY ON 5.3.2.2

Legislation is in place which is enforced by the environmental regulators to protect both the natural environment and residents surrounding sites through the planning process and implementation of project specific environmental management schemes.

Regulators have a diverse range of responsibilities and enforcement powers. Their responsibilities are as follows:

<i>Local Authority</i>	<i>Noise, air quality, traffic, the planning process and contaminated land</i>
<i>Environmental regulators</i>	<i>Discharges to land and controlled waters, waste, water abstraction control, nature conservation</i>
<i>Nature conservation organizations</i>	<i>Designated ecological, geological and geomorphological sites and protected species</i>
<i>Heritage bodies</i>	<i>Designated archaeological and heritage sites</i>

5.3.2.3 Community relations

Developing effective communication and consultation with the local community is important to minimize the likelihood of nuisance (e.g. noise and vibration, dust, waste etc.) and should be instigated at the earliest opportunity; if members of the community are engaged and kept informed throughout a project they are less likely to complain.

Public consultation is particularly important on larger projects where prolonged periods of disturbance and/or significant changes to the environment or landscape are likely to occur.

Typical liaisons should include:

- community representatives e.g. town or parish councillors;
- occupants of sensitive buildings e.g. schools, nursing homes, hospitals, etc.;
- local residents and/or resident groups;
- national and local interest groups, e.g. environmental groups, trade associations, etc.

5.4 Environmental considerations

Environmental considerations should be assessed by the designer, who should judge where the balance of importance lies for a given scheme.

NOTE 1 Which aspect takes priority will change from scheme to scheme and with time as legislation and other factors change.

At many sites there are environmental restrictions on the works that will be permitted (SSSI, protected species, etc); at all sites the earthworks

should be planned to consider environmental considerations and thus reduce the environmental impact of the scheme.

NOTE 2 There is environmental and planning legislation to be complied with during the development of an earthworks design. This includes, but is not limited to Environmental Assessments, Environmental Statements and Habitat Surveys [12].

Affected parties such as Natural England should be consulted to ascertain environmental requirements during and post construction, including translocation of endangered species and acceptable environmental mitigation works.

The earthworks design team should be aware of the overall environmental objective to minimize environmental impact, which is often summarized by the slogan “rethink, reduce, reuse, recycle”, which reflects the priority of each option. These options in the case of earthworks may be applied in various ways including the following:

- rethink – e.g. consider whether any particular course of action is actually necessary;
- reduce – e.g. reduce the overall environmental impact, such as reducing the volume of material excavated or the requirement for aggregate;
- reuse – e.g. reuse all earthworks materials generated on a project whenever possible (within earthworks or landscaping), or use of stabilisation techniques to render materials suitable for reuse;
- recycle – e.g. recycling of materials between sites such as use of secondary aggregates.

Whenever management of waste materials forms part of an earthwork scheme, input should be obtained from an environmental specialist to address aspects such as waste classification and assessment for hazardous substances; this will necessitate appropriate testing as part of the site investigation (SI). In addition to the requirements of BS EN 1997-2:2007, the SI should consider the following issues that are of particular significance to earthworks.

- Existing ground and re-use of materials:
 - suitability as construction materials (classification), including “relationship testing” (see 6.1.3);
 - aggressivity of ground (see BRE SD1 [13]);
 - contamination testing sufficient to develop the conceptual model of the site and inform appropriate risk assessment.
- Modification of marginal materials for use as engineering fills.
- Enhancement of soils as growing media.

NOTE 3 This standard does not cover the treatment of contaminated materials.

Any materials that might require off-site disposal should be tested to ascertain their classification under relevant requirements, including:

- waste acceptance criteria;
- European waste classification; and
- suitability for re-use off-site (subject to acceptance by EA).

NOTE 4 The above list is a general guide and any assessment has to satisfy the requirements of current UK environmental and waste management legislation (and likely developments in the short term).

The project team should be aware of any changes to relevant legislation, and that industry best practice will change to accommodate regulatory revision. Consultation with relevant regulatory authorities is recommended at the earliest opportunity.

The tax imposed on disposal of waste and the importing of primary aggregate can change; up-to-date information should be obtained from HM Revenue and Customs.

Designers should be aware of the potentially significant commercial impact of designs requiring off-site disposal of waste. Treatment of waste can significantly increase the proportion of material classified as inert, thus reducing the potential cost of disposal. The following treatment methods may be cost-effective depending on the condition of the materials awaiting disposal.

- physical sorting/screening to separate inert and contaminated materials;
- pH adjustment to immobilize heavy metals;
- stabilizing with hydraulic binders;
- bioremediation;
- sparging or similar techniques to reduce volatiles;
- soil washing.

During the design of any investigation, testing should be specified to assist in the selection of a treatment process suitable for dealing with arisings from the site.

NOTE 5 Legislation [14] requires that all waste is pre-treated prior to disposal.

Environmental impacts and impact mitigation that should be considered include the following:

- habitat loss due to earthworks and opportunities for the creation/improvement of habitat provision;
- sustainable drainage systems (SUDS; a drainage option to enhance biodiversity, amongst other benefits, as described in 7.5.5);
- loose tipping (reduced compaction) of sub-soil, which should be practiced, where possible, to promote re-vegetation;
- geodiversity can be enhanced by retention of exposures in cutting, pre-existing spoils of mineralogical/palaeontological interest as an educational resource (some cuttings are designated as Regionally Important Geological and Geomorphological Sites [RIGS]);
- plan from an early stage to use local resources (e.g. use of locally available recycled and secondary aggregates) and to avoid unnecessary disposal of materials off site (e.g. inclusion of environmental bunding to avoid disposal of surplus material);

NOTE 6 Planning in this way greatly increases the potential for these options to be successful at detailed design stage.

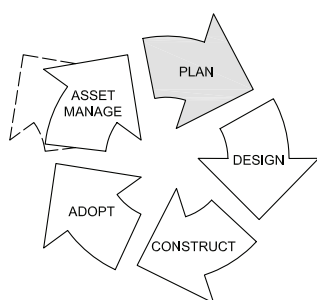
- the physical footprint of an earthwork can be modified by design to mitigate adverse impacts of land take; a narrow footprint achieved by using reinforced soil will reduce land take in areas where level ground is required for development; a wide footprint, with gentle batter slopes, may permit agricultural use of the slopes; and

- potential impact of the earthworks form on future air and noise quality in the immediate area.

NOTE 7 There are opportunities to apply innovation to achieve environmental sustainability objectives, e.g. use of tyre bales (see TRL report PPR080 [15]).

5.5 Environmental impact assessment (EIA)

The process of preparing the EIA for a scheme should be led by suitably experienced environmental specialists who are aware of both the nature of the proposed engineering works and the current legislation covering this area of work. Earthworks professionals should have sufficient understanding of the process to provide input to the EIA and use the completed assessment (see [12]).



6 Site conditions and investigations

6.1 Site investigation for earthworks

6.1.1 Scope

The site investigation [comprising desk study, geomorphological mapping, topographic survey and physical ground investigation (GI) as appropriate] should be planned and implemented to ensure that the site conditions are adequately understood. In particular it is essential that the GI provides adequate and sufficient information for design and construction, and for investigation of existing earthworks and slopes (BS EN 1997-1:2004, 2.1.8 and 2.1.9 have to be satisfied in this regard).

NOTE The degree of the investigation will depend on the complexity of the project. For small-scaled earthworks, such as simple re-grading or reshaping of the ground profile, a simple trial-pitting investigation with in-situ testing might be appropriate; for larger schemes a more detailed geotechnical investigation is likely to be needed.

The scope of the site investigation should be determined by the project's geotechnical engineer with consideration given to all parties that will be involved with the earthworks in future, particularly the earthworks contractor (input from whom at an early stage is to be encouraged).

The recommendations and guidance within this section apply to both new construction and the investigation of existing earthworks; the GI should be planned to suit the project.

6.1.2 Planning

NOTE BS EN 1997-2:2007 identifies the need to plan the investigation to provide sufficient information for the different stages of design; further guidance is given in BS 5930:1999+A1.

The geotechnical designer should be consulted and contribute to all stages of the investigation.

When planning a phase of ground investigation, it is important to consider the needs of all those who will use the data obtained, at a later phase of the scheme, e.g. if the project will go to design and build tender, what information will be required to evaluate the scheme?

If the observational method is the design approach, certain requirements for the GI should be addressed at an early stage (see BS EN 1997-1:2004, CIRIA R185 [16]). However, the GI and design process for earthworks projects should be responsive to ground conditions encountered, so there should always be an element of observation and response. Therefore, the GI may be planned accordingly from an early stage, which can be advantageous, (e.g. position of instrumentation to ensure future use through the project).

The investigation of failed earthworks should be given special consideration when planning investigations. Of paramount importance are the on-going risks posed by the failed earthwork and the economic implications for the earthworks owner. The investigation should be designed to identify the failure mechanism and provide sufficient information to design an engineered solution to the problem.

Existing earthworks that will be subject to modification e.g. embankment widening should be given special consideration when designing a GI to take account of the potential for differential settlement, increased porewater pressures and reduced slope stability.

6.1.3 Testing

The testing regime, both in situ and within the laboratory, should form an integral part of any GI to enable site characterization and material classification for both design and construction purposes.

The choice of testing method to control the works should maximize the volume of usable material and minimize disruption to the works. The use of laboratory relationship testing (MCV : mc : dry density : strength) in advance of the works is advisable; this approach will often enable control of earthworks by MCV which minimizes disruption of the works.

Relationship testing to identify an acceptable range of moisture contents for the material to be used in earthworks should be undertaken under Category 2 and Category 3 projects. An adequate amount of soil should be recovered as bulk samples to enable a range of testing to be undertaken at a set of moisture contents, allowing an assessment to be made of the acceptable range of moisture content of the material for use in earthworks (see HA44/91 [17] and HA70/94 [18] for details). An assessment may then be made for the appropriate treatment of marginal material falling outside of this acceptable moisture content range, or one of the other required material suitability criteria such as grading. Additional testing may be required as part of this assessment of marginal materials.

Table 2 provides a summary of the earthworks testing that is most commonly used to follow the SHW [1], and appropriate tests from Table 2 should be selected for the investigation and design stage.

COMMENTARY ON 6.1.3

The nature of soils tests undertaken for earthworks are detailed within BS EN 1997-2:2007 and the various supporting documents. Experience has shown that more meaningful results can be obtained for earthworks by modifying tests to take account of local soils and conditions. This subclause is provided to identify the tests most commonly recommended to control earthworks (especially when following the SHW [1]) and to comment on some of the main issues that ought to be considered both during GI and design of the earthworks.

Further details on some of the issues are provided within HA 44/91 [17] and HA 70/94 [18], which provide information on the selection and assessment of appropriate testing for the control of earthworks and the design assumptions that form part of the SHW [1]. This topic is summarized in 7.6.4. The information on earthworks control shown in Table 2 is only provided to illustrate how the test might be taken into the construction stage.

6.1.4 Geotechnical reporting

Site investigation and design should be undertaken as a phased process in order to ensure that the ground conditions of the site are adequately understood for the works to be constructed (see *Site Investigation in Construction* [20] for guidance⁶⁾). The geotechnical reporting should be dependent on the complexity of the scheme, as identified in the subsequent sections, but in most cases this will also follow a phased process.

All phases of the geotechnical reporting should feed back into the geotechnical risk register (see Clause 4) as appropriate to the scale of the project.

NOTE The reporting approach required to satisfy BS EN 1997 (both parts) includes the preparation of reports at various phases in the ground investigation, design and construction process. These are set out in 6.3, 6.4 and Figure 2 in the context of earthworks.

6.1.5 Soil and rock descriptions and classification

6.1.5.1 Description

Soils should be described in accordance with BS EN ISO 14688-1:2002 and BS EN ISO 14688-2:2004.

Rocks should be described in accordance with BS EN ISO 14689-1.

6.1.5.2 Classification

Earthworks materials should be classified in accordance with Table 6/1 of SHW [1].

The classification of the materials involved during excavation, transportation and deposition can vary, hence soil/fill may be classified at any of the following stages:

- in situ – classification in undisturbed condition prior to excavation;
- on excavation – disturbed material after excavation; and
- on deposition – classification following placing and prior to compaction.

The option for classifying soil/fill should be selected which is most appropriate for the particular project logistics and materials to be worked with, and should maximize the potential to win suitable fill from the site.

Classification should be based on both descriptive determination and standard use of materials, such as SHW [1] Table 6/1.

⁶⁾ Currently under review.

Table 2 Indicative earthworks tests by test type and material type

Test type	Material type	Applicability			Uses		Comments
		Design	Construction control	Stabilization and re-use			
Natural moisture content	F,M,C,R	✓	✓	✓	Classification and compaction control		Used for comparison with laboratory moisture content values determined as part of relationship testing suites
Particle size distribution	F,M,C,R	✓	✓	✓	Classification		Used for determining fill material grouping and assisting compaction plant selection
Atterberg limits	F,M,C	✓	✗	✓	Classification		Used to derive behavioural characteristics and preliminary engineering properties in cohesive fill, e.g. A-line plot in BS 5930:1999+A1, Figure 18
Particle density	F,M,C,R	✓	✓	✓	Classification		Used for determining loadings, bulking and compaction control (air voids determination) of fill materials
2.5 kg rammer compaction	F,M	✓	✗ ^{A)}	✓			
4.5 kg rammer compaction	F,M	✓	✗ ^{A)}	✓	Determination of dry density/moisture relationship		Used to specify moisture content limits for use of material as fill (may be used in conjunction with CBR Test)
Vibrating hammer compaction	M,C	✓	✗ ^{A)}	✓			A) Additional tests are commonly undertaken during construction to validate the relationship.
Moisture condition value (MCV)	F,M	✓	✓	✗	Classification and compaction control		Used for assessing fill material suitability for specification/design and in-situ monitoring of sources of fill
California bearing ratio (CBR)	F,M	✓	✓	✓	Formation strength determination		Used to determine pavement construction thicknesses and assist in-situ compaction control during construction
Undrained shear strength parameters	F,M	✓	✗	✓	Design of earthworks subject to undrained loading conditions		Temporary slope and foundation design for construction purposes; assessment of plant trafficability; permanent works constructed with cohesive soils, subject to rapid loading
Drained shear strength parameters	F,M	✓	✗	✗	Design of earthworks subject to drained loading conditions		Slope and foundation design for long-term temporary or permanent works; temporary works constructed with granular soils
Los Angeles abrasion test	M,C	✓	✗	✗	Design of permanent works		Used for selected fill materials
Plate load test	F,M,C	✓	✓	✓	Design and compaction control		Used for assessment of settlement characteristics and bearing capacity at formation level and of compacted fills
Dynamic cone penetrometer	F,M,C	✓	✓	✓	Design and compaction control		Used for designing foundations (bearing capacity), formations and in-situ compaction monitoring

Table 2 Indicative earthworks tests by test type and material type (*continued*)

Test type	Material type	Applicability		Uses		Comments
		Design	Construction control	Stabilization and re-use		
MEXE probe	F,M,C	✓	✓	✓	Design and compaction control	Used for designing foundations (bearing capacity), formations and in-situ compaction monitoring
Dynamic plate load test	F,M,C	✓	✓	✓	Design and compaction control	Used for designing foundations, formations and in-situ compaction monitoring. The form of test adopted for pavement foundation design is the lightweight falling weight deflectometer (LWD).
Clegg impact soil tester	F,M	✓	✓	✓	Formation strength determination	Used to determine pavement construction thicknesses and assist in-situ compaction control during construction
Field density test	F,M	✓	✓	✓	Design and compaction control	Used to determine in-situ densities and assist in-compaction control during construction
pH, SO ₄ , Cl	F,M,C,R	✓	✓	✓	Design and confirmation during construction	Determination of aggressive ground conditions for cementitious products and buried metallic structures and elements (see BRE SD1 [13])
Redox potential/resistivity	F,M,C,R	✓	✓	✓	Design and confirmation during construction	Determination of aggressive ground conditions for buried metallic structures and elements
Chemical analysis	F,M,C,R	✓	✓	✓	Design risk assessments and safe construction	Determination of toxic elements/compounds for environmental and health and safety control during construction
Waste acceptance criteria	F,M,C,R	✓	✓	✓	Design and confirmation during construction	Determination of chemical characteristics for disposal offsite to landfill

Key

F = soils not containing more than 10% retained on a 2 mm test sieve

M = soils containing more than 10% retained on a 2 mm test sieve but not containing more than 10% retained on a 20 mm test sieve

C = soils containing more than 10% retained on a 20 mm test sieve but not containing more than 10% retained on a 37.5 mm test sieve

R = zone "X" material and rock fill

Based upon BS 1377 (all parts) and *Manual of Laboratory Soil Testing* [19].

6.2 Site characterization and investigation

NOTE 1 See BS EN 1997-2:2007, 2.1 and 2.2.

The stages of a geotechnical investigation should include a desk study (sometimes referred to as a preliminary sources study), a preliminary investigation, to characterize the site in general terms, and wherever required, subsequent phases of design investigation to provide detailed information for specific elements of the design. These phases are briefly described within the following subclauses.

NOTE 2 Under certain circumstances, it is impracticable to use a phased approach to a geotechnical site investigation beyond the desk study. The ground investigation phases have to be combined. This is particularly true for investigations in a railway environment or major trunk road where opportunities for access are limited.

6.3 Desk study

6.3.1 General

A desk study is an essential prerequisite for planning a ground investigation and informing subsequent design. Some general guidance on desk studies that should be consulted is provided in BS 5930:1999+A1 and BS 1997-2:2007, 2.1.1.

Feedback (through an iterative process) should be made from the desk study to the overall conception and design of the project, where warranted by its complexity. Preliminary information may be fed back into the project risk register at an early stage to aid conceptual design and preliminary planning application(s).

The desk study for earthworks projects should include an evaluation of both internal and external geotechnical influences on the project. This may include both current and historical land use, ground stability, an examination of existing earthworks, surface and groundwater conditions, contamination, etc. The desk study should include an adequate site-based inspection of the site and adjacent land by the geotechnical engineer; the use of geomorphological mapping techniques for this activity can prove advantageous.

The desk study should provide a design for the preliminary investigation based on the information available at that point in time.

The desk study should enable an initial input to geotechnical and project risk register(s) (see Figure 2).

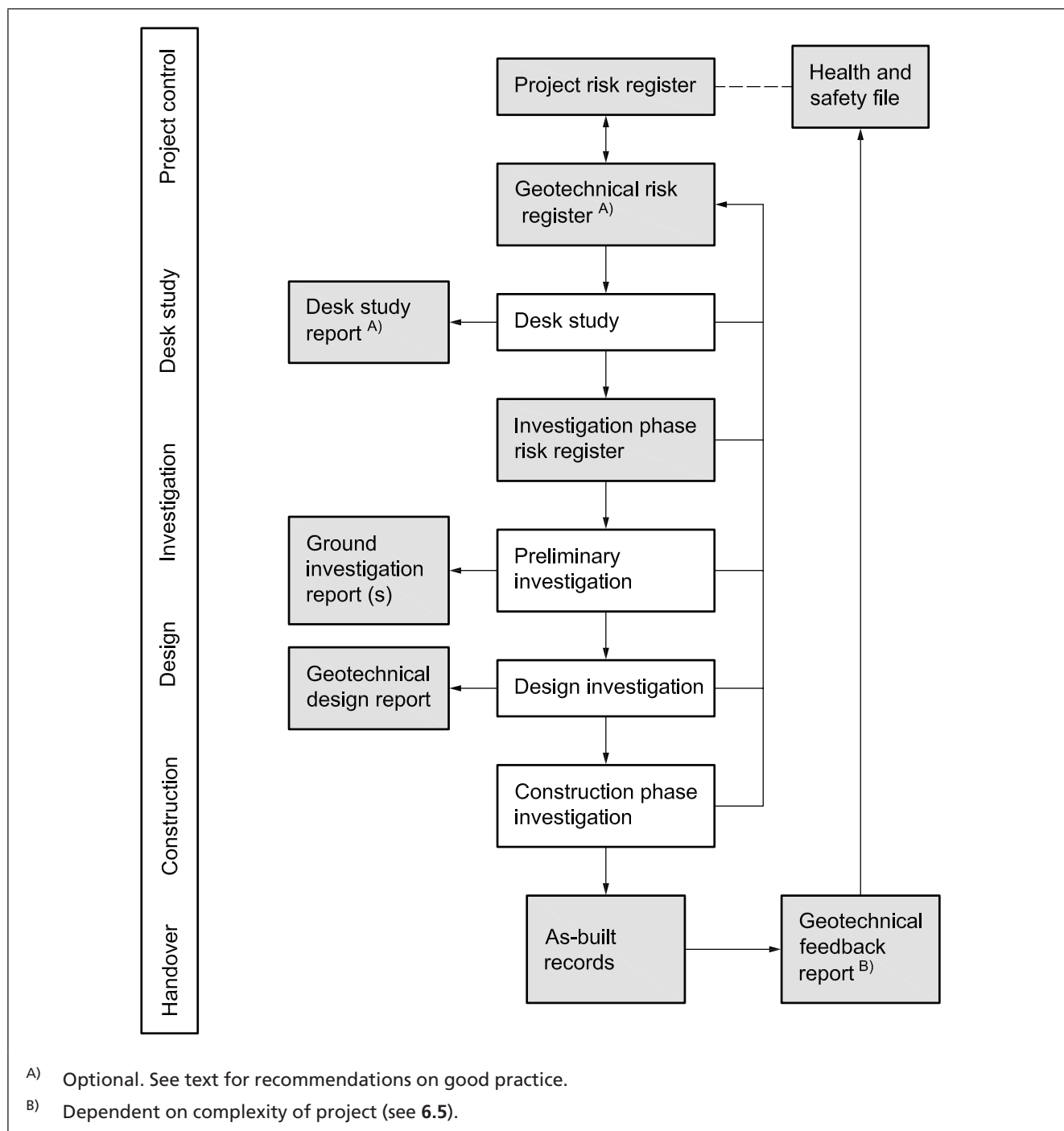
Where appropriate an initial review may be undertaken based on the desk study information obtained of the various engineering options available for the scheme; when undertaken this generally forms the first phase of the project planning process.

6.3.2 Extent of desk study

6.3.2.1 General

The scope and extent of a desk study should be commensurate with the proposed works. The desk study for widening of an existing highway embankment may be limited to a walk-over survey and review of existing as-built drawings, whereas the desk study for 5 km of new flood defence embankment through an industrial area may require enquiries of multiple sources.

Figure 2 The iterative feedback processes of a site investigation



6.3.2.2 Existing earthworks

A desk study for projects involving existing earthworks should seek to make maximum use of construction, inspection and maintenance records available for the earthwork, and give consideration to common performance problems with that particular type of earthwork (e.g. likely method of construction given age of earthwork).

A thorough search of drainage plans and records is essential when dealing with existing earthworks. Any maintenance records of infrastructure supported by the earthworks should be included in the desk study as these might highlight areas with potential underlying problems.

6.3.2.3 New-build earthworks

In addition to the recommendations of 6.3.1, attention should be paid to areas where land drains are present, as these might require interception. Topographical low points should be identified as these might be underlain by relatively soft, recent or weathered soils. The presence and extent of alluvium should be gleaned from geological maps and memoirs; this is particularly important when studying flood plains of large, mature river systems.

6.3.2.4 Reporting of desk study

COMMENTARY ON 6.3.2.4

In the UK, the desk study report (DSR) may be presented as a preliminary sources study report (PSSR) in accordance with HD 22/08 [11].

The presentation of desk study findings should be dependent on the scale of the project. Desk study information should be collated in a coherent form and be made available for all interested parties, including designers of ground investigations and designers of the earthworks. This may be achieved by the preparation of a formal DSR. However, if a DSR is not prepared, the information should be collated within the project file and made available to the project team; one option is to include the data within the ground investigation report (GIR).

NOTE The potential benefit of compiling the desk study information and interpretation into a formal DSR depends on the size of the project and complexity of the ground conditions. The DSR can be an important document in itself and may be used for preliminary planning applications, design, etc.

6.4 Ground investigation

6.4.1 Preliminary investigation

COMMENTARY ON 6.4.1

See BS EN 1997-2:2007, 2.3.

The preliminary investigation is undertaken once the general scope of the project has been identified to provide an overall understanding of the ground conditions at the site and thereby minimize the geotechnical risk associated with the project (see Clause 4). The outputs from the preliminary investigation are likely to include some or all of the following:

- *ground investigation report;*
- *feedback to geotechnical risk register;*
- *feedback to project risk register (option analysis);*
- *proposals for design investigation.*

6.4.1.1 Purpose and extent of preliminary investigations

The specific parameters that should be evaluated depend on the nature of the works; with different priorities being applied to new build, modification and repairs. Four broad categories of earthworks related assessment should be considered.

- a) Shear strength and stiffness (consolidation) characteristics of in-situ soils that will be subject to changes of in-situ stress; e.g. soils below formation level in cut zones and fill zones, soils that will form batter slopes in areas of cut. This may include existing earthworks that are to be incorporated into new works; e.g. raising of an existing embankment.

- b) Characteristics of fill materials after compaction. This may include classification of fills in terms of SHW Table 6/1 and establishing relationships between moisture content and other compaction control related parameters. It may include estimation of shear strength and stiffness parameters.
- c) Assessment of ground for excavation. This may cover estimation of volumes of suitable, or potentially suitable, fill material available from identified borrow areas or other sources. The assessment may also include rippability of material to be excavated to form cuttings.
- d) Assessment of the hydrological and/or hydrogeological conditions that may influence the design and construction of the earthworks.

A preliminary investigation for existing slopes and earthworks should include:

- a check for existence of shear zones;
- gathering data to enable back analysis of existing slopes for comparison with laboratory parameters;
- highlighting potential access difficulties for remedial works; and
- consideration of the possible need for specialist plant.

6.4.1.2 Reporting of preliminary investigations

Preliminary investigations should be presented within the GIR. The degree of detail in the GIR should be consistent with the objective of the particular phase of ground investigation.

As required by BS EN 1997-2:2007, 6.1, the GIR should include both factual information and evaluation.

COMMENTARY ON 6.4.1.2

BS EN 1997-2:2007, 6.1 states that "the GIR shall form a part of the Geotechnical Design Report". It goes on to state that:

"(2) The Ground Investigation Report shall consist of the following:

– a presentation of all appropriate geotechnical information including geological features and relevant data; [commonly referred to as a "factual report" in the UK]

– a geotechnical evaluation of the information, stating the assumptions made in the interpretation of the test results. [historically included within an "interpretative report" in the UK]."

"(3) The information may be presented as one or as separate parts."

6.4.2 Design investigation

COMMENTARY ON 6.4.2

Design investigation is undertaken to clarify ground conditions at selected locations or to clarify particular issues to enable the design (there can be as many phases of design investigation as are required).

See BS EN 1997-2:2007, 2.4.

6.4.2.1 General

The design investigation should concentrate on specific aspects of the geotechnical design that mitigate the risks identified in the geotechnical/project risk register(s), where appropriate.

6.4.2.2 Purpose and extent of design investigation

The design investigation for an earthworks project should include classification testing, soil relationship testing and marginal materials assessment (see 6.1.3). The design investigation should elaborate on and develop the classification and relationship testing undertaken as part of the preliminary investigation.

At this stage the designer may give consideration to the likely approach to the earthworks and arrange for appropriate specialist testing. Sufficient numbers of large bulk samples, particularly from trial pits, should be specified in the design investigation to enable extensive laboratory trials to be carried out. These may include strength and stiffness testing and undertaking stabilization trials (modification of marginal materials at varying additions of binder). These trials consume large volumes of material but it should always be considered that reducing the number and size of bulk samples can be a false economy; this is especially the case where factors beyond the control of the project team preclude further GI.

Where appropriate, the design investigation should include the installation of monitoring instrumentation such as piezometers and inclinometers. Further guidance is given in Dunnicliff [21].

The design investigation should be designed to meet and, if needs be, enhance/expand on the requirements of BS EN 1997-2:2007.

6.4.2.3 Reporting of design investigation

A geotechnical design report (GDR) should conform to BS EN 1997-1:2004, 2.8. HD 22/08 [11] has been drafted in compliance with BS EN 1997 (both parts), with a particular emphasis on the requirements of a major earthworks project.

The following items might be of particular relevance to an earthworks design and should be considered for inclusion in the GDR as appropriate.

- a) Draft specification of fill materials. This may be in the form of draft numbered appendices in accordance with the SHW [1]. In particular, the designer should be looking to set upper and lower limits for identified parameters in Table 6/1.
- b) Formalized charts for relationship testing of fills.
- c) The proposed scheme for monitoring and measuring compliance with the specification. This may be in the form of a draft Appendix 1/5 in accordance with the SHW [1].
- d) Deformation limits and associated monitoring requirements if an observational design approach is being followed. The designer should make clear any assumptions made in the design. In particular, the GDR should make clear any assumed sequence of works as this may affect the routing of haul roads or selection of plant.

6.4.3 Further investigation during construction

It should be appreciated that no ground investigation, however carefully done, ever examines more than a very small proportion of the ground. It is essential that the soil conditions revealed during progress of the excavations are checked to see that they correspond with those forming the basis for earthworks design as interpreted from

the ground investigation; it might be necessary to undertake further investigation to determine the extent of anomalous conditions.

NOTE Guidance is given in BS 5930:1999+A1.

6.5 Geotechnical feedback

The iterative feedback process that should be followed, including the production of a geotechnical feedback report (GFR) if appropriate, is illustrated in Figure 2.

COMMENTARY ON 6.5

BS EN 1997-2:2007 does not include a requirement for a GFR to be produced to record the construction works phase of a project, however BS EN 1997-2:2007, Annex B, under "Execution of works", does advise a "report from inspection, supervision and monitoring", and this would at least in part be satisfied by the production of a GFR. As stated at Clause 4, the GFR is a document of value for capturing geotechnical data from an earthworks project (this would also be a valuable part of the CDM health and safety file).

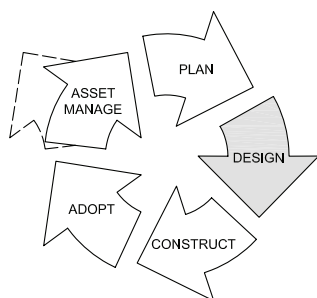
A GFR is usually prepared on completion of construction.

Generally two broad types of information are contained in a GFR:

- a) geotechnical design changes during construction; and
- b) results of monitoring and testing conducted during construction.

It forms an ideal vehicle that may be used for reporting the results of compliance testing (e.g. in-situ density measurement, plate load tests), distribution of fill classes within an earthwork, and data from monitoring instruments (e.g. piezometers, inclinometers, settlement gauges). The report should give a commentary on how the results of testing and monitoring have compared with the expected or specified range of values. This is particularly important where the observational method of design has been applied. The commentary should include a time-line that allows a chronological understanding of events, e.g. relating instrument readings to filling operations.

NOTE The benefits of preparing a geotechnical feedback report are both for maintenance of the site and to capture "lessons learned" for future projects: as-built drawings alone generally do not capture all the information relevant to earthworks that will be relevant to future maintenance of the earthwork; an appropriate range of information to be included within the geotechnical feedback report is detailed within HD22/08 [11].



7 Design of earthworks

7.1 General

7.1.1 Introduction

Clause 7 should be consulted for information relating to the design of earthworks that are intended to be self supporting (excavations requiring temporary support are covered in Clause 13).

Earthworks that incorporate some degree of reinforcement should satisfy the recommendations of BS 8006-1 or BS 8006-2, in addition to this standard, where relevant.

7.1.2 Concept of BS EN 1997-1:2004 geotechnical categories

Earthworks should be designed in accordance with the principles and application rules of BS EN 1997-1:2004, which is intended to be used in the United Kingdom as a general basis for the geotechnical aspects of the design of buildings and civil engineering works.

NOTE BS EN 1997-1:2004, Section 5 (fill, dewatering, ground improvement and reinforcement), Section 11 (overall stability) and Section 12 (embankments) are particularly relevant to the design of earthworks whilst Section 1, (general), Section 2 (basis of geotechnical design) and Section 3 (geotechnical data) provide guidance on the application of design rules and the selection of parameters used in the design.

BS EN 1997-1:2004, 2.1 introduces the concept of limit state design to earthworks, typically the ultimate limit state (ULS) and the serviceability limit state (SLS); earthworks should be designed such that the relevant limit states are not exceeded during their design life.

COMMENTARY ON 7.1.2

Instead of using global factors of safety that have been adopted previously in traditional earthworks design, BS EN 1997-1:2004 adopts the approach of applying partial factors to actions (loads) and the effects of actions, materials (soil parameters) and earth resistances.

To establish the geotechnical design requirements, BS EN 1997-1:2004 recommends the classification of geotechnical structures into three geotechnical categories according to the complexity of the structure, the ground conditions, the loading and the level of risk that is acceptable. The Geotechnical Categories are used to establish the extent of site investigation required and the amount of input to the design. The Geotechnical Category should be checked throughout the design and constructions process and the Category amended if necessary as information becomes available.

Geotechnical Category 1 – for small and relatively simple structures for which it is possible to ensure that the fundamental requirements will be satisfied on the basis of experience and qualitative geotechnical investigations. Category 1 structures carry negligible risk.

Geotechnical Category 2 – encompasses conventional geotechnical structures with no exceptional risk or difficult ground or soil loading conditions, most earthworks will fall into this category.

Geotechnical Category 3 – includes very large or unusual structures which are not included in Geotechnical Categories 1 and 2. Examples of such Category 3 structures (which could be earthworks) are given as: structures involving abnormal risks or unusual or exceptionally difficult ground or loading conditions; structures in highly seismic areas; structures in areas of ground instability or persistent ground movements that require separate investigation or special measures.

BS EN 1997-1:2004 permits the use of three design approaches but the National Annex adopts Design Approach 1 (DA1). DA1 includes two combinations and the application of these combinations is discussed in 7.3.3.

7.1.3 Design input at GI stage

The scope and extent of the ground investigation should reflect the BS EN 1997-1:2004 Geotechnical Category of the project. For Category 2 or 3 projects the GI will normally be undertaken as a staged process (see 6.4); this process might require a certain amount of design to be

undertaken as the GI develops in order to confirm the scope of certain aspects of the GI.

7.1.4 Detailed design using GI data

The detailed design should be undertaken based on the GI data obtained; BS EN 1997-1:2004, 2.8 requires that a geotechnical design report is prepared (see 6.4.2) that identifies how the GI data has been interpreted into the design including justification for the design values adopted for soil and rock properties. The geotechnical design report should also identify ground condition issues that should be checked during construction.

7.1.5 Geotechnical certification

Consideration should be given to the adoption of a formal system of geotechnical certification (see 4.3), for recording formally the Geotechnical Category and for certifying the design process at specific stages; BS EN 1997-1:2004 Section 4 provides recommendations for the procedures to be adopted for supervision, monitoring and checking during the construction process.

7.2 Factors governing the stability of slopes

7.2.1 Introduction

As part of the design of earthwork slopes, the designer should assess aspects that can be considered by calculation (e.g. stability of slopes, potential for adverse settlement, scour), and also other potential modes of failure that might require engineering judgement and precedence to be used rather than relying entirely on calculation (e.g. erosion, influence of animals or vegetation). The site observation, modelling of ground conditions and the risk assessment process is an important part of the design of earthworks to help identify potential modes of failure.

The overall stability of slopes should be assessed based on the requirements given in BS EN 1997-1:2004, 11.5, and designers should consider whether it is appropriate to assess deformation of the ground as detailed in BS EN 1997-1:2004, 12.6. The applicable actions for different design situations should be considered (BS EN 1997-1:2004, 11.3) which for earthworks can include external influences such as earthquakes and pile driving.

7.2.2 Materials and ground conditions

For the purpose of making a preliminary assessment of stability conditions and for guidance in formulating a field or laboratory testing programme, consideration should be given to previous relevant experience and published information to obtain an indication of the behaviour of a particular type of soil when excavated to form slopes and platforms. The parameters used to define shearing resistance should be obtained from back analysis or from appropriate field or laboratory tests which take account of the permeability of the mass of material and also of the stress changes which take place in the material, both in the short and long term, as a result of excavating for slopes and platforms.

The designer should review the nature of the materials that form or influence the stability of the slope and consider which attributes of the material could have a significant influence on the potential modes of failure:

- grading/permeability of the soil (coarse soil or fine soil, or intermediate soil that may show attributes of both) and groundwater conditions, these factors tend to dominate the likely form of instability within soil slopes in most general cases; further discussion on this topic is provided at 7.2.4;
- previous stress conditions are of particular importance to fine grained soils which can be in a normally consolidated or overconsolidated state;
- presence of geological structure within the soil or rock, such as bedding planes, laminations, fissures or other discontinuities;
- presence of zones of contrasting permeability;
- presence of historical slip surfaces where previous movement was sufficient to generate smooth (slickensided) surface with a "residual" shear strength in clay soils;
- weathering of fine grained soils or rocks leading to a reduction in strength of the material often resulting in zones of weakness (e.g. along fissures in soil or rock, and can lead to karst conditions in limestone), and the leaching of minerals under prolonged seepage or other weathering phenomena can lead to the development of sensitive soils prone to collapse on disturbance in some normally consolidated fine soils.
- influence of human activities in the form of mining.

Once the potential modes of failure have been identified, each should be assessed by a method suitable for the material type and reflecting the geotechnical category of the structure. Details of methods of analysis are provided within soils mechanics references such as Bromhead [22].

7.2.3 Actions

NOTE 1 Load cases for earthworks design usually comprise externally applied actions and the self-weight of the earth structure itself.

For externally applied actions, details should be obtained of static, transient and dynamic loads that might be applied to the earthworks. A minimum surcharge of 10 kN/m² should be applied to the surface at the top of embankments and cuttings where the external action might adversely affect the stability of the slope.

NOTE 2 This requirement is not in addition to any specific live loading of equal or greater magnitude that is included within the slope design model.

The minimum surcharge should be considered as a permanent load and appropriate partial factors should be applied to the action.

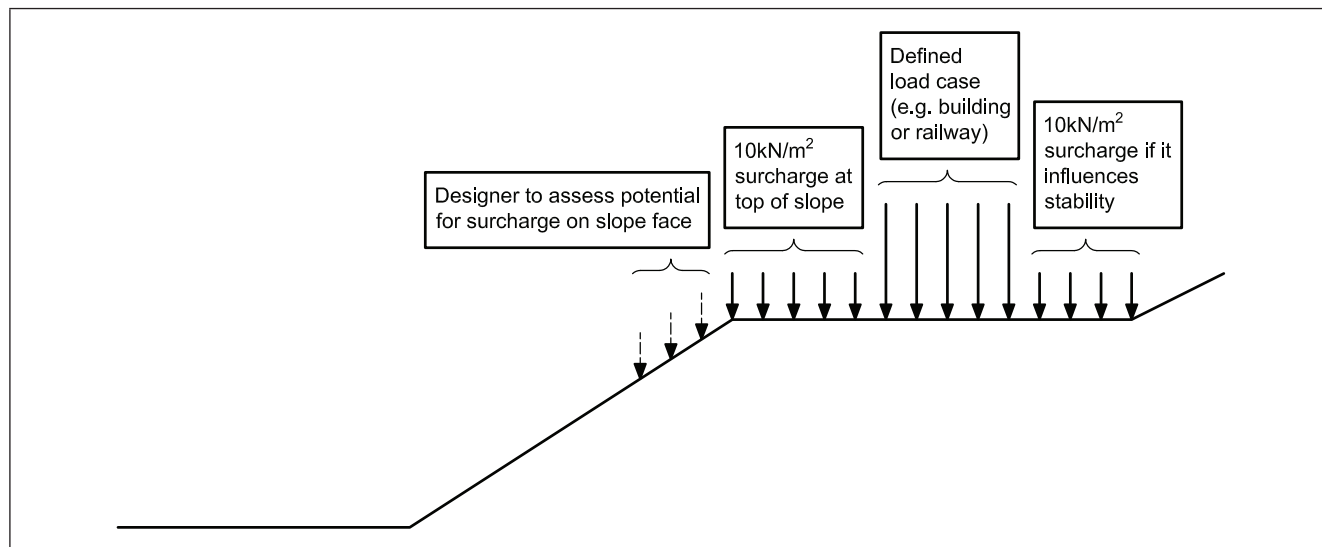
Additional surcharge loading should be applied to take account of actions resulting from loads imposed on the earthworks during construction and during the design life. The surcharges applied to the earthworks may be classified as:

- uniformly distributed load (UDL) consisting of a continuous load on the surface, this may be a defined load case (e.g. railway industry RL or RU loading), or a general surcharge to represent construction plant, stored materials (10 kN/m² minimum).

- concentrated loads (e.g. pad foundations);
- line loads (e.g. strip footings);
- dynamic loads (e.g. impact loads), these are generally modelled as a UDL. In some specific cases impact loads may be modelled as point loads.

The combination of these load cases can result in a combination of applicable surcharge being applied to the slope; the designer should identify the applicable surcharges to be modelled. This situation is illustrated in Figure 3 as a possible design scenario.

Figure 3 Example of possible surcharge combination on a slope



In the absence of more exact calculations, the nominal loads due to live load surcharge may be taken from Table 3.

Table 3 Nominal load due to live surcharge

Standard load	Uniformly distributed load UDL kN/m ²	Typical applicable design cases
No specified load case	10	Earthworks slopes where maintenance equipment might present an adverse load case.
Typical highway loading	10	Common practice is to assume this value. Extreme cases agreed on a site-specific basis.
RL loading	30 on area occupied by tracks	London Underground and other light rail systems
RU loading	50 on area occupied by tracks (see Note 3)	"Rail universal" used for all standard UK railways

NOTE 3 RU loading is included in Table 3 because this has formed the basis of design for many years. However, in future UK railways will change their standards to apply surcharge loads in accordance with Eurocodes. It remains important that the designer considers the likely distribution of load below the track and the dispersal of load with depth through the soil.

A clear understanding of the loads that will be applied to the earthworks should be obtained from the asset owner; otherwise, the

designer should identify to the asset owner the restrictions on surface loading of the earthworks.

The designer should give consideration to the duration of applied loads and the selection of appropriate soil parameters for the assessment of slope stability, i.e. whether drained or undrained conditions are appropriate for the duration of the load. The designer should consider that some surcharges might exist for short periods of time only, in which case, the ground can respond in an undrained manner during the entire period of the application of the surcharge.

The dead load may be assumed to be the load of the earthwork.

NOTE 4 BS EN 1997-1:2004 distinguishes between permanent loads and variable loads that are applied to the slope in so far as different partial factors are applied to each type of load. Permanent loads will, for example, comprise structures and buildings whilst variable loads will normally consist of traffic or rail loading or other transient loads. Loads imposed by structures and buildings will consist of both the dead load from the structure and live load applied to the structure; unless the live load forms a significant proportion of the total load from the structure the load applied to the earthworks by the structure may be assumed to be permanent. An example of where variable load from a structure might need to be applied separately to the dead load is in the case of a service reservoir located at the crest of a slope. In this case the loading from the water might be greater than the dead load of the structure and the load might fluctuate throughout the design life of the structure.

Care should be exercised when applying surcharge loads to the slope face since these loads can act either favourably or unfavourably (i.e. they might contribute to either destabilizing forces or to restoring forces) depending on their position on the slope.

7.2.4 Selection of parameters

7.2.4.1 General

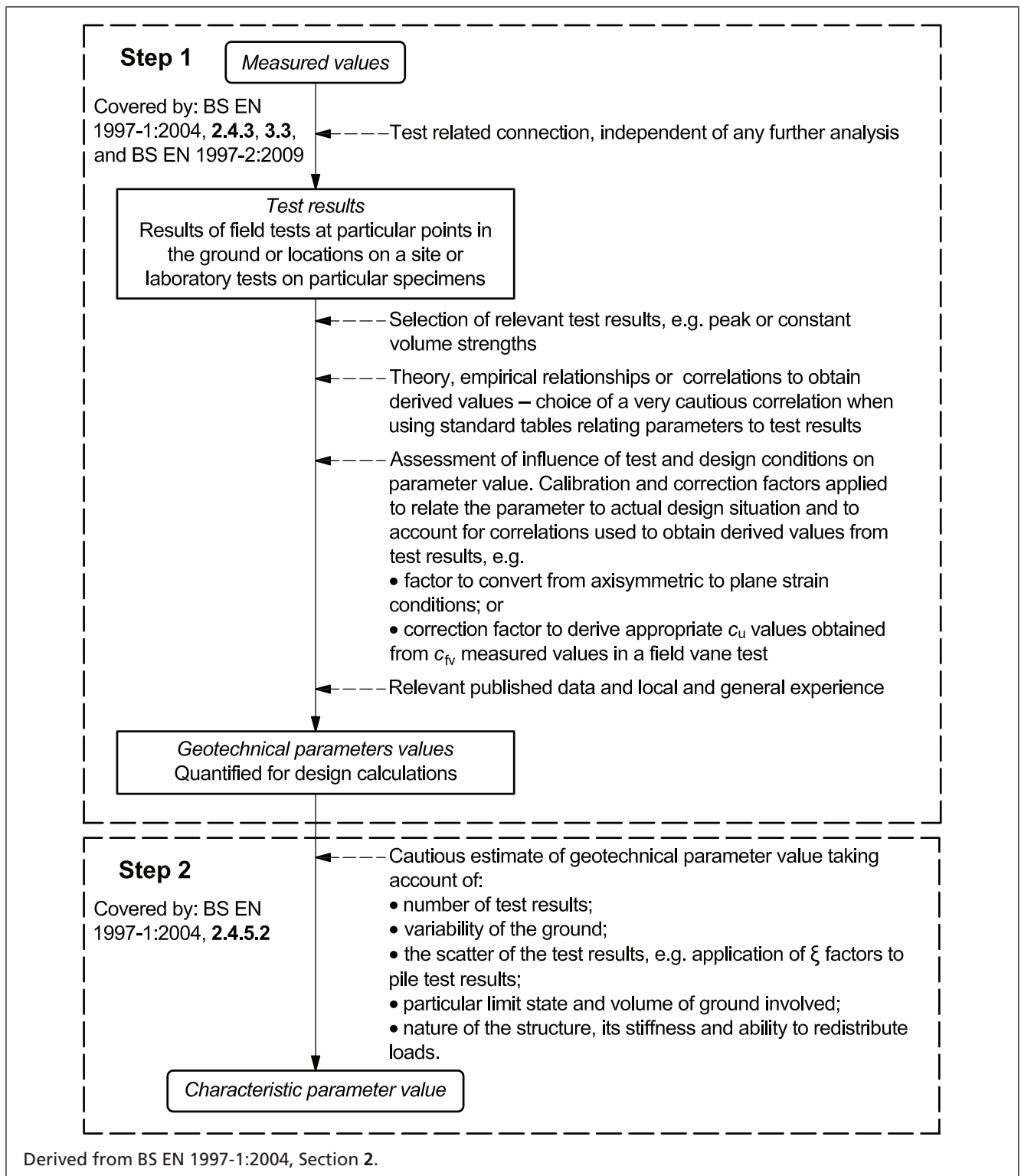
NOTE 1 BS EN 1997-1:2004, 2.4.3 requires ground properties to be obtained from test results or from other relevant data. Such data might be, for example, back calculations, empirical or theoretical correlations, field measurements and observations or published data.

The assessment of geotechnical parameters from tests should take account of the difference between the properties obtained from the tests and those that govern the behaviour of the mass of the ground forming the embankment or cutting.

NOTE 2 Potential influencing factors: for slope design the potential for strain-softening behaviour or brittleness can be of particular concern for cohesive soils as a significant loss of resistance can occur if the peak strength is exceeded locally (see 7.2.7 and Table A.1 regarding progressive failure).

Characteristic values for the geotechnical parameters should be selected in accordance with BS EN 1997-1:2004, 2.4.5. The process of selecting the characteristic values from the ground properties may be divided into two stages. First, establish the values of the appropriate ground properties and second, select the characteristic value as a cautious estimate of the value affecting the limit state under consideration taking into account all relevant information. This process is illustrated in Figure 4.

Figure 4 General procedure for determining characteristic values from measured values



When selecting the characteristic values, due account should be taken of the items listed in BS EN 1997-1:2004, **2.4.5.2**, the following items are of particular relevance to slope design:

- geological, historical and other background data;
- the amount of measured data relating to the parameter value under consideration;