

BS 8002:2015



BSI Standards Publication

Code of practice for earth retaining structures

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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 30 June 2015. 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.

Supersession

Together with BS EN 1997-1:2004+A1:2013, this British Standard supersedes BS 8002:1994, which is withdrawn.

Relationship with other publications

BS 8002 gives non-contradictory, complementary information for use with BS EN 1997 and its UK National Annexes.

Information about this document

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

- the revised text is fully compatible with the current version of Eurocode 7 (BS EN 1997);
- guidance is given on designing earth retaining structures according to limit state principles using partial factors;
- guidance is given on the selection of design parameters for soils;
- guidance is given on model factors to be applied to prop loads determined by calculation;
- the revised text reflects advances in earth retaining structure technology over the past 30 years.

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.

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.

1 Scope

This British Standard gives recommendations for the design and construction of earth retaining structures to support ground at slopes steeper than the ground would naturally assume. It provides non-contradictory, complementary information for use in conjunction with BS EN 1997 and its UK National Annex.

Clause 4 gives general recommendations for the design and construction of all types of earth retaining structures; Clause 5, Clause 6, and Clause 7 give specific recommendations for the design and construction of gravity walls, semi-gravity walls, and embedded walls (respectively); and Clause 8 gives specific recommendations for the design and construction of cofferdams, basements, and strutted excavations.

Annex A gives specific recommendations for the design and construction of deadman anchors.

Annex B gives information about specific geological formations encountered in the UK.

NOTE 1 This standard does not cover the design and construction of anchors (other than deadman anchors), for which see BS 8081.

NOTE 2 This standard does not cover the design and construction of earthworks, for which see BS 6031.

NOTE 3 This standard does not cover the design and construction of foundations, for which see BS 8004.

NOTE 4 This standard does not cover the design and construction of maritime works, for which see BS 6349.

NOTE 5 This standard does not cover the design and construction of earth retaining structures constructed using strengthened or reinforced soil walls, for which see BS 8006.

2 Normative references

Standards publications

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.

BS 65, *Specification for vitrified clay pipes, fittings and ducts, also flexible mechanical joints for use solely with surface water pipes and fittings*

BS 437, *Specification for cast iron drain pipes, fittings and their joints for socketed and socketless systems*

BS 4449, *Steel for the reinforcement of concrete – Weldable reinforcing steel – Bar, coil and decoiled product – Specification*

BS 4660, *Thermoplastics ancillary fittings of nominal sizes 110 and 160 for below ground gravity drainage and sewerage*

BS 4729, *Clay and calcium silicate bricks of special shapes and sizes – Recommendations*

BS 4962, *Specification for plastics pipes and fittings for use as subsoil field drains*

BS 5480, *Specification for glass reinforced plastics (GRP) pipes, joints and fittings for use for water supply or sewerage*

BS 5481, *Specification for unplasticized PVC pipe and fittings for gravity sewers*

- BS 5642-2, *Sills, copings and cappings – Part 2: Specification for copings and cappings of precast concrete, cast stone, clayware, slate and natural stone*
- BS 5837, *Trees in relation to design, demolition and construction – Recommendations*
- BS 5911 (all parts), *Concrete pipes and ancillary concrete products*
- BS 5930, *Code of practice for site investigation*
- BS 5975, *Code of practice for temporary works procedures and the permissible stress design of falsework*
- BS 6031:2009, *Code of practice for earthworks*
- BS 6349 (all parts), *Maritime works*¹⁾
- BS 8004:2015, *Code of practice for foundations*
- BS 8006-1:2010, *Code of practice for strengthened/reinforced soils and other fills*
- BS 8006-2, *Code of practice for strengthened/reinforced soils – Part 2: Soil nail design*
- BS 8081, *Code of practice for ground anchors*
- BS 8102, *Code of practice for protection of below ground structures against water from the ground*
- BS 8215, *Code of practice for design and installation of damp-proof courses in masonry construction*
- BS 8417, *Preservation of wood – Code of practice*
- BS 8500-1:2015, *Concrete – Complementary British Standard to BS EN 206-1 – Part 1: Method of specifying and guidance for the specifier*
- BS 8500-2²⁾, *Concrete – Complementary British Standard to BS EN 206-1 – Part 2: Specification for constituent materials and concrete*
- BS 10175, *Investigation of potentially contaminated sites – Code of practice*
- BS EN 206:2013, *Concrete – Specification, performance, production and conformity*
- BS EN 295 (all parts), *Vitrified clay pipe systems for drains and sewers*
- BS EN 335:2013, *Durability of wood and wood-based products – Use classes: definitions, application to solid wood and wood-based products*
- BS EN 350-2, *Durability of wood and wood-based products – Natural durability of solid wood – Part 2: Guide to the natural durability of and treatability of selected wood species of importance in Europe*
- BS EN 351-1, *Durability of wood and wood-based products – Preservative-treated solid wood – Part 1: Classification of preservative penetration and retention*
- BS EN 460, *Durability of wood and wood-based products – Natural durability of solid wood – Guide to the durability requirements for wood to be used in hazard classes*
- BS EN 598, *Ductile iron pipes, fittings, accessories and their joints for sewerage applications – Requirements and test methods*
- BS EN 771-1, *Specification for masonry units – Part 1: Clay masonry units*

¹⁾ Specific references are made to the following part: BS 6349-2:2010, *Maritime works – Part 2: General – Code of practice for the design of quay walls, jetties and dolphins*

²⁾ Informative reference is made to BS 8500-2:2015.

- BS EN 771-2, *Specification for masonry units – Part 2: Calcium silicate masonry units*
- BS EN 771-3, *Specification for masonry units – Part 3: Aggregate concrete masonry units*
- BS EN 771-4, *Specification for masonry units – Part 4: Autoclaved aerated concrete masonry units*
- BS EN 771-5, *Specification for masonry units – Part 5: Manufactured stone masonry units*
- BS EN 771-6, *Specification for masonry units – Part 6: Natural stone masonry units*
- BS EN 845-1, *Specification for ancillary components for masonry – Part 1: Wall ties, tension straps, hangers and brackets*
- BS EN 1401 (all parts), *Plastic piping systems for non-pressure underground drainage and sewerage*
- BS EN 1536, *Execution of special geotechnical works – Bored piles*³⁾
- BS EN 1538, *Execution of special geotechnical works – Diaphragm walls*⁴⁾
- BS EN 1852-1, *Plastics piping systems for nonpressure underground drainage and sewerage – Polypropylene (PP) – Part 1: Specifications for pipes, fittings and the system*
- BS EN 1916, *Concrete pipes and fittings, unreinforced, steel fibre and reinforced*
- BS EN 1990:2002+A1:2005, *Eurocode – Basis of structural design*
- BS EN 1991, *Eurocode 1: Actions on structures*⁵⁾
- BS EN 1992 (all parts), *Eurocode 2: Design of concrete structures*⁶⁾
- BS EN 1993 (all parts), *Eurocode 3: Design of steel structures*⁷⁾
- BS EN 1995 (all parts), *Eurocode 5: Design of timber structures*⁸⁾

³⁾ Informative reference is made to BS EN 1536:2010.

⁴⁾ Informative reference is made to BS EN 1538:2010.

⁵⁾ Specific references are made to the following parts:

- BS EN 1991-1-1:2002, *Eurocode 1: Actions on structures – Part 1-1: Densities, self-weight, imposed loads for buildings*;
- BS EN 1991-1-6:2005, *Eurocode 1: Actions on structures – Part 1-6: General actions – Actions during execution*;
- BS EN 1991-2:2003, *Eurocode 1: Actions on structures – Part 2: Traffic loads on bridges*.

⁶⁾ Specific references are made to the following parts:

- BS EN 1992-1-1:2004+A1:2014, *Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings*;
- BS EN 1992-3, *Eurocode 2: Design of concrete structures – Part 3: Liquid retaining and containing structures*.

⁷⁾ Specific references are made to the following parts:

- BS EN 1993-1-1, *Eurocode 3: Design of steel structures – Part 1-1: General rules and rules for buildings*;
- BS EN 1993-5, *Eurocode 3: Design of steel structures – Part 5: Piling*.

⁸⁾ Specific references are made to the following part: BS EN 1995-1-1, *Eurocode 5: Design of timber structures – Part 1-1: General – Common rules and rules for buildings*.

- BS EN 1996 (all parts), *Eurocode 6: Design of masonry structures*⁹⁾
- 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 10025, *Hot rolled products of structural steels*
- BS EN 10080, *Steel for the reinforcement of concrete – Weldable reinforcing steel – General*
- BS EN 10210, *Hot finished structural hollow sections of non-alloy and fine grain steels*
- BS EN 10218-1:2012, *Steel wire and wire products – General – Part 1: Test methods*
- BS EN 10218-2:2012, *Steel wire and wire products – General – Part 2: Wire dimensions and tolerances*
- BS EN 10219, *Cold formed welded structural hollow sections of non-alloy and fine grain steels*
- BS EN 10223-3:2013, *Steel wire and wire products for fencing and netting – Part 3: Hexagonal steel wire mesh products for civil engineering purposes*
- BS EN 10223-8:2013, *Steel wire and wire products for fencing and netting – Part 8: Welded mesh gabion products*
- BS EN 10244-2:2009, *Steel wire and wire products – Non-ferrous metallic coatings on steel wire – Part 2: Zinc or zinc alloy coatings*
- BS EN 10245-1, *Steel wire and wire products – Organic coatings on steel wire – Part 1: General Rules*
- BS EN 10245-2, *Steel wire and wire products – Organic coatings on steel wire – Part 2: PVC finished wire*
- BS EN 10245-3, *Steel wire and wire products – Organic coatings on steel wire – Part 3: PE coated wire*
- BS EN 10245-5, *Steel wire and wire products – Organic coatings on steel wire – Part 5: Polyamide coated wire*
- BS EN 10248, *Hot rolled sheet piling of non alloy steels*
- BS EN 10249, *Cold formed sheet piling of non alloy steels*
- BS EN 12063, *Execution of special geotechnical work – Sheet pile walls*
- BS EN 12666-1, *Plastics piping systems for non-pressure underground drainage and sewerage – Polyethylene (PE) – Part 1: Specifications for pipes, fittings and the system*
- BS EN 13369, *Common rules for precast concrete products*
- BS EN 13670, *Execution of concrete structures*
- BS EN 14199, *Execution of special geotechnical works – Micropiles*
- BS EN 15258, *Precast concrete products – Retaining wall elements*

⁹⁾ Specific references are made to the following parts:

- BS EN 1996-1-1, *Eurocode 6: Design of masonry structures – Part 1-1: General rules for reinforced and unreinforced masonry structures*;
- BS EN 1996-2, *Eurocode 6: Design of masonry structures – Part 2: Design considerations, selection of materials and execution of masonry*.

BS EN ISO 1461, *Hot dip galvanized coatings on fabricated iron and steel articles – Specifications and test methods*

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

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

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

prEN ISO 22477 (all parts), *Geotechnical investigation and testing – Testing of geotechnical structures*¹⁰⁾

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

NA to BS EN 1991-2:2003, *UK National Annex to Eurocode 1: Actions on structures – Part 2: Traffic loads on bridges*

NA to BS EN 1997-1:2004+A1:2013, *UK National Annex to Eurocode 7: Geotechnical design – Part 1: General rules*

NA to BS EN 1993-1-1, *UK National Annex to Eurocode 3: Design of steel structures – Part 1-1: General rules and rules for buildings*

NA to BS EN 1993-5, *UK National Annex to Eurocode 3: Design of steel structures – Part 5: Piling*

PD 6694-1:2011, *Recommendations for the design of structures subject to traffic loading to BS EN 1997-1:2004*

PD 6697:2010, *Recommendations for the design of masonry structures to BS EN 1996-1-1 and BS EN 1996-2*

Other publications

[N1]PREENE, M., ROBERTS, T.O.L., POWRIE, W., and DYER, M.R. *Groundwater control: design and practice*, 2nd edition (CIRIA Report C750). London: CIRIA, 2015, ISBN 978-0860175155.

[N2]BURLAND, J.B., BROMS, B.B., and de MELLO, V.F.B. *Behaviour of foundations and structures*, State-of-the-Art Report, Session 2, Proc. 9th International Conference on Soil Mechanics and Foundation Engineering, 1977, Tokyo, Vol. 2, pp 495–546.

[N3]GABA, A.R., SIMPSON, B., POWRIE, W., and BEADMAN, D.R. *Embedded retaining walls – guidance for economic design* (CIRIA C580), London: CIRIA, 2003, ISBN 0-86017-580-4.¹¹⁾

[N4]INSTITUTION OF CIVIL ENGINEERS. *ICE Specification for piling and embedded retaining walls* (2nd edition, 2007), London: Thomas Telford Publishing, ISBN 978-0-7277-3358-0.

¹⁰⁾ In preparation.

¹¹⁾ It is anticipated that a revised version of C580 (with a new number, C760) will be published in 2016.

3 Terms and definitions

For the purposes of this British Standard, the terms and definitions given in BS EN 1990, BS EN 1997, and the following apply.

NOTE Symbols are defined locally to the equations where they are used.

3.1 cofferdam

3.1.1 cofferdam

watertight enclosure pumped dry to permit construction below the waterline

3.1.2 cellular cofferdam

cofferdam consisting of a series of filled cells of circular or other shape in plan

3.1.3 double-wall cofferdam

cofferdam formed by a wall consisting of two parallel walls tied together, with filling between them and which is usually self-supporting against external pressure

3.1.4 land cofferdam

cofferdam constructed from a land surface

3.1.5 water cofferdam

cofferdam constructed in open water

3.2 crib wall

3.2.1 crib wall

retaining wall built up of individual elements to form a series of box-like cells into which infill (which acts as an integral part of the structure) is placed

3.2.2 crib cell

box-like structure formed from headers and stretchers into which infill is placed

3.2.3 header

element that runs normal to the line of a crib wall

3.2.4 stretcher

element that runs along the line of a crib wall

3.2.5 infill

material placed within crib cells

3.2.6 backfill

material located behind a crib wall

3.3 earth pressure coefficients

3.3.1 earth pressure coefficient, K

ratio of horizontal effective stress to vertical effective stress

3.3.2 active earth pressure coefficient, K_a

earth pressure coefficient under active conditions

3.3.3 passive earth pressure coefficient, K_p

earth pressure coefficient under passive conditions

3.3.4 at-rest earth pressure coefficient, K_0

earth pressure coefficient under at-rest conditions

3.4 earth pressure

3.4.1 active earth pressure

minimum value of earth pressure that occurs when the structure moves away from the ground

NOTE The movement required to mobilize active earth pressure is usually within the structure's serviceability limit state.

3.4.2 passive earth pressure

maximum earth pressure generated by the ground when the structure moves towards the ground

NOTE The movement required to mobilize passive earth pressure is often outside the structure's serviceability limit state.

3.4.3 at-rest earth pressure

earth pressure acting on a structure when there is no relative movement between it and the ground

3.5 working platform

temporary structure that provides a foundation for construction plant

4 General rules

4.1 Choice and design of earth retaining structure

4.1.1 General

4.1.1.1 The design of earth retaining structures should conform to BS EN 1997-1 and this clause (4).

NOTE Guidance on geotechnical design, construction, and verification can be found in the ICE manual of geotechnical engineering (2012), Volume II [1].

4.1.1.2 The following should be taken into account when choosing a suitable earth retaining structure:

- the location of the wall, its position relative to other structures, and the amount of construction space available;
- the necessity or otherwise to confine the support system within the site boundaries;
- the proposed height of the wall and the topography of the ground, both before and after construction;
- ground conditions;
- groundwater, standing water, flood and tidal conditions;
- the extent of acceptable ground movement during construction and in service;
- the effect of movement of the earth retaining structure on existing services and supported structures;
- external live loading;
- the availability of materials;
- appearance;
- the required design life; and
- maintenance requirements.

NOTE 1 Guidance on the selection of a suitable earth retaining structure can be found in the ICE manual of geotechnical engineering (2012), Volume II, Chapter 62 [1] and in Earth Pressure and Earth-Retaining Structures (3rd edition), Chapter 6 [2] and in CIRIA Report C580 [N3]¹²⁾.

NOTE 2 Guidance on geotechnical engineering principles, problematic soils, and site investigation can be found in the ICE manual of geotechnical engineering (2012), Volume I [3].

4.1.1.3 The design of deadman anchors should conform to Annex A.

4.1.1.4 The design of maritime works should conform to BS 6349.

4.1.1.5 The design of reinforced soil retaining walls and abutments should conform to BS 8006-1:2010, Section 6.

4.1.2 Gravity retaining walls

The design of gravity retaining walls should conform to **4.1.1.1** and Clause 5.

NOTE Gravity retaining walls are earth retaining structures that depend primarily on their own self-weight (and that of any enclosed material) to support the retained ground and any structures or loads placed upon it.

4.1.3 Semi-gravity retaining walls

The design of semi-gravity retaining walls should conform to **4.1.1.1** and Clause 6.

NOTE Semi-gravity retaining walls are earth retaining structures that depend partly on their own self-weight (and that of any enclosed material) and partly on their structural resistance to support the retained ground and any structures or loads placed upon it.

4.1.4 Embedded retaining walls

The design of embedded retaining walls should conform to **4.1.1.1** and Clause 7.

NOTE Embedded retaining walls are earth retaining structures that depend primarily on lateral earth resistance and their own structural resistance (plus that of any structural supports) to support the retained ground and any structures or loads placed upon it.

4.1.5 Cofferdams

The design of cofferdams should conform to **4.1.1.1** and Clause 8.

NOTE Cofferdams are composite earth retaining structures that act in some ways like a gravity retaining wall and in other ways like an embedded retaining wall.

4.1.6 Basements and strutted excavations

The design of basements and strutted excavations should conform to **4.1.1.1** and Clause 8.

NOTE Basements and strutted excavations are underground constructions that incorporate earth retaining structures.

4.2 Basis of geotechnical design

NOTE Attention is drawn to The Construction (Design and Management) Regulations 2015 [4], with regards to health and safety requirements for construction works, in particular:

¹²⁾ It is anticipated that a revised version of C580 (with a new number, C760) will be published in 2016.

- *Regulation 9, duties of designers;*
- *Regulation 11, duties of the principal designer in relation to the pre-construction phase; and*
- *Regulation 22, excavations.*

4.2.1 Design requirements

4.2.1.1 Geotechnical data and investigation

4.2.1.1.1 Geotechnical data should be obtained in accordance with BS EN 1997-1:2004+A1:2013, Clause 3.

4.2.1.1.2 Particular attention should be given to the requirements of BS EN 1997-1:2004+A1:2013, 3.1.

4.2.1.1.3 Geotechnical investigations should conform to BS EN 1997-1:2004+A1:2013, 3.2.

4.2.1.1.4 Ground investigations should conform to BS EN 1997-2 and BS 5930. Information about the site from the desk study should be used to supplement that obtained in any new ground investigation.

4.2.1.1.5 Sampling and testing of contaminated ground and groundwater should conform to BS 10175 and BS ISO 5667-11.

4.2.1.1.6 The spacing and depth of site investigations for earth retaining structures should conform to BS EN 1997-2:2007, B.3, and this subclause (4.2.1).

4.2.1.1.7 The location of investigation points for an earth retaining structure should be representative of the line of the structure and should encompass both the retained and the retaining material. The number of investigation points should be sufficient to establish ground conditions, and any variability in those conditions, along the length of the earth retaining structure.

4.2.1.1.8 The spacing of investigation points along the length of an earth retaining structure should be no greater than 20 m, unless the ground conditions can be shown to be sufficiently uniform to justify a greater spacing.

4.2.1.1.9 For gravity and semi-gravity earth retaining structures, the depth of investigation below the planned base of the foundation (z_a) should conform to recommendations given in BS 8004:2015, 4.2.1.1, for low-rise buildings, namely:

$$z_a \geq \begin{cases} 2b_f \\ 3\text{m} \end{cases} \quad (1)$$

where:

b_f is the smaller side length of the wall's foundation (on plan).

4.2.1.1.10 For embedded earth retaining structures, the depth of investigation below the base of the excavation (z_a) should satisfy:

$$z_a \geq \begin{cases} 2H & \text{for an unsupported structure} \\ H + 2\text{ m} & \text{for a supported structure} \end{cases} \quad (2)$$

where:

H is the retained height.

4.2.1.1.11 If ground anchors are proposed to support an embedded retaining wall, the investigation should be of sufficient depth and lateral extent to provide data on the ground in which the anchors attain their bond lengths in accordance with BS 8081.

4.2.1.1.12 The presence of trees and large shrubs should be recorded during the course of the ground investigation, so that decisions can be taken concerning their retention or subsequent removal.

NOTE Guidance on site investigation can be found in the ICE manual of geotechnical engineering (2012), Volume I, Section 4: Site investigation [3] and in the NHBC Design Guide, Efficient design of piled foundations for low rise housing (2010), Section 4: Site investigation [5].

4.2.2 Design situations

4.2.2.1 Design situations should be specified in accordance with BS EN 1997-1:2004+A1:2013, 2.2.

4.2.2.2 Design situations for earth retaining structures should include:

- the conditions given in BS EN 1997-1:2004+A1:2013, 9.3.3;
- the geometry of the structure and neighbouring ground;
- material characteristics of the structure, e.g. following corrosion;
- effects due to the environment within which the design is set;
- groundwater levels, including their variations due to the effects of dewatering, possible flooding, or failure of any drainage system;
- overdredging of river or sea beds;
- deepening of river or sea beds due to scour;
- increase in hydrostatic head due to drawdown; and
- water levels in the tidal or flood range.

To conform to BS EN 1990, exceptional conditions involving local failure (such as a burst water pipe that continues to leak after the burst) should be classified as accidental design situations.

4.2.3 Design considerations

COMMENTARY ON 4.2.3

Design and construction considerations for earth retaining structures are given in BS EN 1997-1:2004+A1:2013, 9.4.1. The design considerations given in this subclause also include more specific examples of the issues that can affect the performance of earth retaining structures.

4.2.3.1 General

The design of an earth retaining structure should consider:

- the design considerations given in BS EN 1997-1:2004+A1:2013, 9.4.1;
- the influence of tidal and flood conditions on groundwater, both for waterfront structures and also for near-shore structures;
- the maximum tidal and flood range to waterfront structures;
- potential or possible surge tides and flood conditions;
- the height, length and angle of approach of waves, and the resulting forces on the structure;
- softening and subsequent loss of strength of fine-grained backfill behind the retaining structure;
- softening and subsequent loss of strength of fine soil beneath formation level in front of the retaining structure;
- ingress of water into fissures formed during hot, dry spells;

- the effect of frost action behind the structure;
- the effect on the earth pressures acting against the structure owing to climatic variations, including:
 - diurnal and seasonal temperature changes (particularly ground freezing);
 - short- and long-term rainfall variations and resulting moisture content changes in the ground;
 - artificially induced climatic changes such as those produced in boiler houses or cold stores;
- trafficking by heavy plant;
- seepage flow around the structure, taking into account layers of markedly different permeability; and
- the possibility that the level of any compacted fill placed against the back of an earth retaining structure might differ during construction from the level of any adjoining fill.

4.2.3.2 Drainage

COMMENTARY ON 4.2.3.2

Provision of suitable drainage is vital to ensure the acceptable performance of an earth retaining structure. Groundwater control is separate from the control of surface water, such as rainfall run-off.

4.2.3.2.1 Drainage should be provided to prevent:

- surface water from entering and eroding the face of any excavations;
- build-up of excessive water pressures during construction in case they have harmful effects upon the foundations;
- instability of slopes.

4.2.3.2.2 Measures taken to prevent groundwater entering a structure should conform to BS 8102. Alternatively, a properly designed and ventilated air space may be provided.

4.2.3.2.3 Sub-surface drainage used to lessen the risk of water ingress into a structure should be designed in accordance with BS 8102.

4.2.3.2.4 Surface water drains should be constructed using one of the types of pipe listed in 4.3.10.

4.2.3.2.5 Drainage systems should be designed for ease of maintenance and renewal during the design working life of the structure.

4.2.3.2.6 Where the safety and serviceability of the works depend on the successful performance of the drainage system, the consequences of failure should be considered and one of the following conditions (or a combination of them) should be applied:

- a maintenance programme specified;
- a drainage system specified that will perform adequately without maintenance; or
- a secondary (“backup”) system specified – for example, a pipe or channel that encloses the primary system – that will prevent any potential leakage from entering the ground beneath or next to the structure.

4.2.3.2.7 The design of drainage systems for earth retaining structures should consider:

- the design considerations given in BS EN 1997-1:2004+A1:2013, 9.4.2;
- changes in groundwater levels (temporary or permanent) owing to construction of the structure.

4.2.3.2.8 A drainage layer might be required to prevent one or more of the phenomena listed in 4.2.3.2.1. Wherever practical, a structure that retains cohesive soil or backfill of medium to low permeability (2×10^{-5} m/s or less) should be provided with a drainage layer at its back face.

4.2.3.2.9 Drainage layers may be constructed from:

- a blanket of rubble or coarse aggregate, clean gravel, or crushed stone;
- hand-placed pervious blocks as dry walling;
- a graded filter drain, where the backfilling consists of fine-grain material;
- a geotextile filter, in combination with a permeable granular material; or
- a geotextile composite (fin-drain), consisting of a geotextile filter fixed to one or both faces of a permeable core.

4.2.3.2.10 The design of filters should conform to CIRIA C750 (2015), Section 3.3 [N1].

4.2.3.2.11 A drainage system should be designed so that water freely exits from drainage layers, through porous land drains or pipes laid at the bottom of the drainage layers, or through weepholes.

4.2.3.2.12 Any impermeable wall or facing should have weepholes provided unless an alternative drainage system is provided or they are designed to resist the water pressure.

NOTE 1 Guidance on surface water control can be found in Groundwater lowering in construction: a practical guide [6], Construction dewatering and groundwater control: new methods and applications [7], and CIRIA C750 [N1].

NOTE 2 Guidance on groundwater control can be found in the ICE manual of geotechnical engineering (2012), Volume II, Chapter 80 [1].

4.2.3.3 Cyclic loading

The following should be taken into account during the design of earth retaining structures subject to cyclic loading:

- degradation of ground strength (leading to ultimate limit states being exceeded at loads below those expected from verifications based on static strength);
- degradation of ground stiffness, leading to an accumulation of permanent foundation displacement ("ratcheting" effects); and
- amplification of loads or movements owing to resonance.

NOTE Guidance on foundations subjected to cyclic and dynamic loads can be found in the ICE manual of geotechnical engineering (2012), Volume II, Chapter 60 [1].

4.2.3.4 Trees

COMMENTARY ON 4.2.3.4

Earth retaining structures built adjacent to existing trees might suffer deleterious effects from the penetration of root-systems. These effects include increased loading on the structure and penetration of roots into joints or drainage systems.

4.2.3.4.1 The principles and procedures to be applied to achieve a harmonious and sustainable relationship between trees (including shrubs and hedges) and structures should conform to BS 5837.

4.2.3.4.2 Earth retaining structures should be designed to accommodate any volumetric changes in clay soils that might be caused by the presence of nearby trees.

NOTE Guidance on building near trees can be found in NHBC Standards, Chapter 4.2 [8].

4.2.3.5 Environmental considerations

The following should be taken into account during the design of earth retaining structures:

- their effect on sensitive species;
- generation and control of noise and dust during construction;
- generation, reuse and disposal of waste materials;
- minimizing the amount of material to be disposed of;
- contaminants entering watercourses (for example, as a result of excavation);
- reuse of clayey soils and weak rocks (such as marls and shales) might require particular attention and expedients, including treatment with cement;
- management of water on site;
- stability of earthworks;
- generation and control of contaminated run-off;
- managing vegetation, especially the risks associated with allowing vegetation to grow unchecked; and
- the carbon footprint of the construction and the use of the structure.

4.2.3.6 Ground improvement

Guidance on ground improvement can be found in BS 8004.

4.3 Materials

NOTE For guidance on specific formations (e.g. London clay, Lambeth group, glacial soils and tills, problematic soils, chalk and Mercia mudstone group), see Annex B.

4.3.1 Soils

4.3.1.1 General

COMMENTARY ON 4.3.1.1

The design of earth retaining structures usually involves effective stress analysis, although, in some circumstances, total stress analysis might be appropriate or necessary for the design of foundations in fine soils. Soil properties are determined as part of the site investigation process but might be supplemented by data from back analysis of comparable earth retaining structures in similar ground conditions.

4.3.1.1.1 The identification and description of soil should conform to BS EN ISO 14688-1.

4.3.1.1.2 The classification of soil should conform to BS EN ISO 14688-2.

4.3.1.1.3 Soil properties should be determined in accordance with BS EN 1997-2 and BS 5930.

4.3.1.1.4 Characteristic soil parameters should be selected in accordance with BS EN 1997-1, based on the results of field and laboratory tests, complemented by well-established experience.

NOTE 1 Guidance on soil description can be found in Soil and rock description in engineering practice [9].

NOTE 2 Information about the behaviour of soils as particulate materials can be found in the ICE manual of geotechnical engineering (2012), Volume I, Chapter 14 [3].

NOTE 3 Information about the strength and deformation behaviour of soils can be found in the ICE manual of geotechnical engineering (2012), Volume I, Chapter 17 [3].

4.3.1.2 Very coarse soils (cobbles and boulders)

COMMENTARY ON 4.3.1.2

Very coarse soils contain a majority (by weight) of particles >63 mm in size. Cobbles are between 63 mm and 200 mm in size; boulders are greater than 200 mm.

Very coarse soils should be identified and classified in accordance with BS EN ISO 14688 and BS 5930.

4.3.1.3 Coarse soils (sands and gravels)

COMMENTARY ON 4.3.1.3

Coarse soils contain a majority (by weight) of particles ≤ 63 mm in size and do not stick together when wet. Sand particles are between 0.063 mm and 2 mm in size; gravels are between 2 mm and 63 mm. Coarse soils cannot be remoulded.

4.3.1.3.1 When establishing the values of parameters for coarse soils, the following should be considered:

- the items listed in BS EN 1997-1:2004+A1:2013, **2.4.3(5)**;
- the weakening of collapsible soils above the groundwater table, owing to percolation or a rise in groundwater levels;
- disturbance of dense deposits owing to unsuitable construction methods; and
- the presence of weaker material.

4.3.1.3.2 For coarse soils above the groundwater table, the suggested values for characteristic weight density given in Figure 1 may be used in the absence of reliable test results.

4.3.1.3.3 For coarse soils below the groundwater table, the suggested values for characteristic weight density given in Figure 2 may be used in the absence of reliable test results.

4.3.1.3.4 A superior value of weight density should be selected when a high value is unfavourable; an inferior value should be selected when a low value is unfavourable.

Figure 1 Suggested values for characteristic weight density of soils above the groundwater table

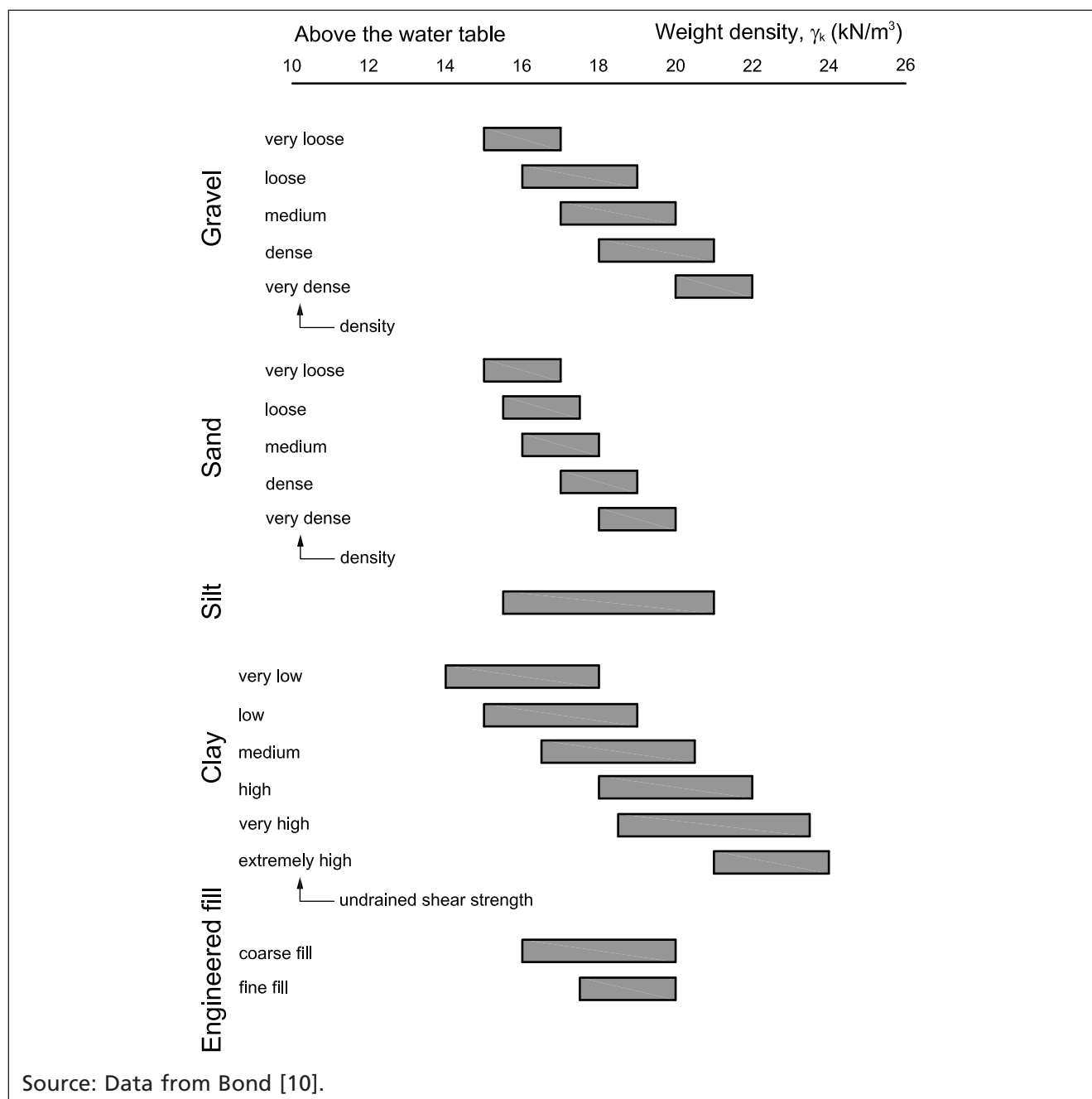
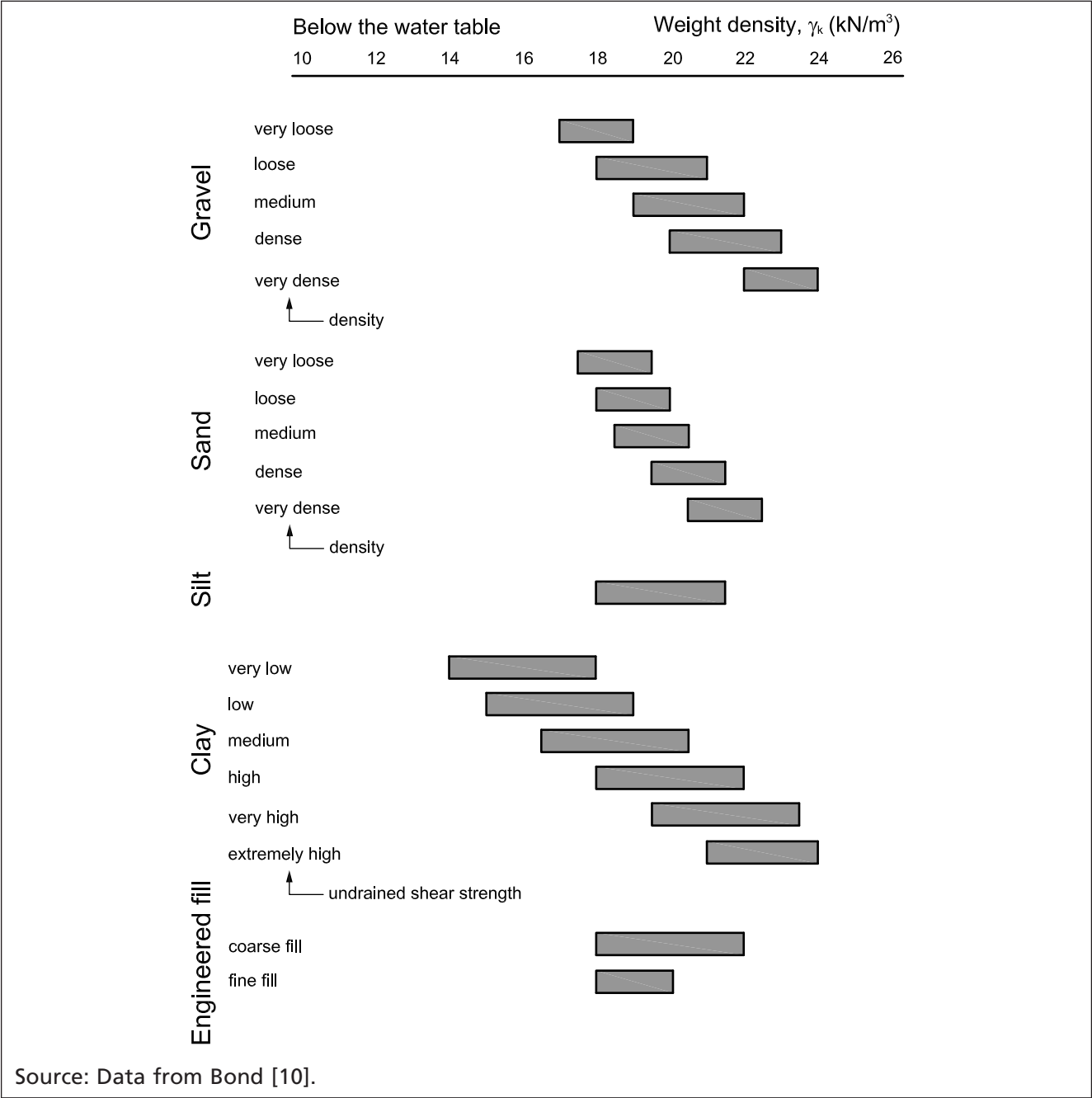


Figure 2 Suggested values for characteristic weight density of soils below the groundwater table



Source: Data from Bond [10].

4.3.1.3.5 For siliceous sands and gravels, the characteristic constant volume (also known as critical state) effective angle of shearing resistance ($\phi'_{cv,k}$) may – in the absence of reliable test results – be estimated from:

$$\phi'_{cv,k} = 30^\circ + \phi'_{ang} + \phi'_{PSD}$$
 (3)

where:

ϕ'_{ang} is contribution to $\phi'_{cv,k}$ from the angularity of the particles; and
 ϕ'_{PSD} is contribution to $\phi'_{cv,k}$ from the soil's particle size distribution.
Values of ϕ'_{ang} and ϕ'_{PSD} are given in Table 1.

4.3.1.3.6 For siliceous sands and gravels with a fines content less than 15%, the characteristic peak effective angle of shearing resistance ($\phi'_{pk,k}$) may be estimated from:

$$\phi'_{pk,k} = \phi'_{cv,k} + \phi'_{dil} \quad (4)$$

where:

ϕ'_{dil} is contribution to $\phi'_{pk,k}$ from soil dilatancy.

Values of ϕ'_{dil} are given in Table 1.

4.3.1.3.7 The value of ϕ'_{dil} may alternatively be estimated from:

$$\phi'_{dil} = n I_R = n [I_D \times \ln(\sigma_c / \sigma'_f) - 1] \quad (5)$$

where:

n is 3 for triaxial strain or 5 for plane strain;

I_R is the soil's relative dilatancy index;

I_D is the soil's density index (defined in BS EN ISO 14688-2);

σ_c is the aggregate crushing stress; and

σ'_f is mean effective stress in the soil at peak strength.

NOTE 1 Bolton [11] defines the relative dilatancy index as $I_R = I_D(Q - I_n p') - 1$, where $Q = I_n \sigma_c$ and $p' = \sigma'_f$.

NOTE 2 Many geotechnical problems can be simplified into a two-dimensional form where the foundation or structure is significantly long in one direction in comparison with other dimensions. Hence, a large number of stability problems involving embankments and cuttings, retaining walls and strip footings are commonly analysed by assuming a plane strain condition in which no deformation occurs in the direction of the long dimension of the foundation or structure.

4.3.1.3.8 The value of σ_c may be taken as 20 MPa for quartz sands, but can be substantially larger for quartz silts, and substantially smaller for carbonate sands (see *The strength and dilatancy of sands* [11]).

4.3.1.3.9 If the fines content of the coarse soil exceeds 25%, then ϕ'_{dil} should be assumed to be zero, unless testing demonstrates otherwise. For coarse soils with fines content between 15% and 25%, ϕ'_{dil} may be determined by linear interpolation.

4.3.1.3.10 If shearing is matrix (i.e. fines) controlled, then ϕ'_{ang} should be assumed to be zero, unless testing demonstrates otherwise. For coarse soils with fines content between 15% and 25%, ϕ'_{ang} may be determined by linear interpolation.

4.3.1.3.11 The characteristic angle of shearing resistance (ϕ'_k) for coarse soils with fines content exceeding 25% should be determined as for fine soils (see **4.3.1.4**).

Table 1 Values of ϕ'_{ang} , ϕ'_{PSD} and ϕ'_{dil} to obtain values of $\phi'_{\text{pk,k}}$ and $\phi'_{\text{cv,k}}$ for siliceous sands and gravels with fines content not exceeding 15%

Soil property	Determined from	Classification	Parameter ^{D)}
Angularity of particles ^{A)}	Visual description of soil	Rounded to well-rounded	$\phi'_{\text{ang}} = 0^\circ$
		Sub-angular to sub-rounded	$\phi'_{\text{ang}} = 2^\circ$
		Very angular to angular	$\phi'_{\text{ang}} = 4^\circ$
Uniformity coefficient, C_U ^{B)}	Soil grading	$C_U < 2$ (evenly graded)	$\phi'_{\text{PSD}} = 0^\circ$
		$2 \leq C_U < 6$ (evenly graded)	$\phi'_{\text{PSD}} = 2^\circ$
		$C_U \geq 6$ (medium to multi graded)	$\phi'_{\text{PSD}} = 4^\circ$
		High C_U (gap graded), with C_U of fines < 2 ^{E)}	$\phi'_{\text{PSD}} = 0^\circ$
		High C_U (gap graded), with $2 \leq C_U$ of fines < 6 ^{E)}	$\phi'_{\text{PSD}} = 2^\circ$
Density index, I_D ^{C)}	Standard penetration test blow count, corrected for energy rating and overburden pressure (N_1) ₆₀	$I_D = 0\%$	$\phi'_{\text{dil}} = 0^\circ$
		$I_D = 25\%$	$\phi'_{\text{dil}} = 0^\circ$
		$I_D = 50\%$	$\phi'_{\text{dil}} = 3^\circ$
		$I_D = 75\%$	$\phi'_{\text{dil}} = 6^\circ$
		$I_D = 100\%$	$\phi'_{\text{dil}} = 9^\circ$

^{A)} Terms for defining particle shape can be found in BS EN ISO 14688-1.

^{B)} The uniformity coefficient C_U is defined in BS EN ISO 14688-2.

^{C)} The density index I_D is defined in BS EN ISO 14688-2. Density terms may be estimated from the results of field tests (e.g. Standard Penetration Test, Cone Penetration Test) using correlations given in BS EN 1997-2.

^{D)} Values of ϕ'_{dil} are appropriate for siliceous sands and gravels reaching failure at a mean effective stress up to 400 kPa. For non-siliceous sands, see *The strength and dilatancy of sands* [11].

^{E)} "Fines" refers to that fraction of the soil whose particle size is less than 0.063 mm.

4.3.1.4 Fine soils (silts and clays)

COMMENTARY ON 4.3.1.4

Fine soils contain a majority (by weight) of particles ≤ 63 mm in size and stick together when wet. Silt particles are between 0.002 mm and 0.063 mm in size; clay particles are smaller than 0.002 mm. Fine soils can be remoulded.

Clay soils with plasticity indices greater than about 20% might exhibit considerably lower angles of shearing resistance than observed at the critical state, if their particles become fully aligned with one another. This phenomenon is termed "sliding shear" to distinguish it from "rolling shear" observed in other soils (including coarse soils and fine soils with plasticity indices less than 20%). The angle of shearing resistance exhibited during sliding shear is called the "residual angle of shearing resistance".

4.3.1.4.1 When establishing the values of parameters for fine soils, the following should be considered, as a minimum:

- the items listed in BS EN 1997-1:2004+A1:2013, 2.4.3(5);
- pre-existing slip surfaces;
- dessication; and
- any changes in stress state, either induced by construction or resulting from the final design condition.

4.3.1.4.2 For fine soils above the groundwater table, the suggested values for characteristic weight density given in Figure 1 may be used in the absence of reliable test results.

4.3.1.4.3 For fine soils below the groundwater table, the suggested values for characteristic weight density given in Figure 2 may be used in the absence of reliable test results.

4.3.1.4.4 A superior value of weight density should be selected when a high value is unfavourable; an inferior value should be selected when a low value is unfavourable.

4.3.1.4.5 In the absence of reliable test data, the characteristic undrained shear strength of a fine soil ($c_{u,k}$) may be estimated from:

$$\frac{c_{u,k}}{p'_v} = k_1 R_O^{k_2} = k_1 \left(\frac{p'_{v,max}}{p'_v} \right)^{k_2} \quad (6)$$

where:

- p'_v is the effective overburden pressure in the ground;
- $p'_{v,max}$ is the maximum effective overburden pressure that the soil has previously been subjected to;
- R_O is the soil's overconsolidation ratio; and
- k_1 and k_2 are constants.

NOTE The ratio c_u/p'_v normally varies with depth (i.e. it is not a constant).

4.3.1.4.6 In the absence of reliable test data, the values of k_1 and k_2 in equation (6) may be taken as 0.23 ± 0.04 and 0.8 respectively (following *New developments in field and laboratory testing of soils* [12]).

4.3.1.4.7 When determining the characteristic undrained strength of high strength fine soils, due allowance should be made for:

- the detrimental effect of any sand or silt partings containing free groundwater;
- the influence of sampling;
- the influence of the method of testing; and
- likely softening on excavation.

4.3.1.4.8 For fine soils, the characteristic constant volume (also known as critical state) effective angle of shearing resistance ($\varphi'_{cv,k}$) may, in the absence of reliable test results, be estimated from:

$$\varphi'_{cv,k} = (42^\circ - 12.5 \log_{10} I_p) \quad \text{for } 5\% \leq I_p \leq 100\% \quad (7)$$

where:

- I_p is the soil's plasticity index (entered as a %).

NOTE 1 Equation (7) is based on an expression proposed by Santamarina and Díaz-Rodríguez [13], which fits data presented by Terzaghi, Peck, and Mesri [14].

NOTE 2 Values of $\varphi'_{cv,k}$ based on this expression are given in Table 2.

Table 2 Values of $\phi'_{cv,k}$ for fine soils from plasticity index

Plasticity index, I_p	Characteristic constant volume angle of shearing resistance $\phi'_{cv,k}$
%	degrees (°)
15	27
30	24
50	21
80	18

NOTE Values of ϕ'_{cv} in excess of 40° have been observed for clays that classify as highly plastic but show signs of bioturbation or the presence of microfossils.

4.3.1.4.9 The characteristic constant volume effective cohesion ($c'_{cv,k}$) should be taken as zero.

4.3.1.4.10 The peak effective angle of shearing resistance (ϕ'_{pk}) may be related to the constant volume effective angle of shearing resistance (ϕ'_{cv}) by:

$$\phi'_{pk} = \phi'_{cv} + \phi'_{dil} \quad (8)$$

where:

ϕ'_{cv} is the soil's constant-volume angle of shearing resistance; and
 ϕ'_{dil} is the contribution to $\phi'_{pk,k}$ from soil dilatancy.

NOTE 1 The value of ϕ'_{dil} for fine soils is not the same as that for coarse soils. For fine soils, it is typically in the range of 0°–4°. No specific guidance is given in this standard for values of ϕ'_{dil} for fine soils.

NOTE 2 Values of ϕ'_{dil} are known to increase with a fine soil's overconsolidation ratio and are greater than or equal to zero.

4.3.1.4.11 When a clay soil is able to undergo "sliding shear" – normally only where pre-existing slip surfaces exist in the ground – then the operational angle of shearing resistance is the clay's residual value (ϕ'_{res}):

$$\phi'_{res} \leq \phi'_{cv} \leq \phi'_{pk} \quad (9)$$

where:

ϕ'_{cv} is the soil's constant-volume angle of shearing resistance; and
 ϕ'_{pk} is the soil's peak angle of shearing resistance.

NOTE Guidance on the undrained strength and the residual shear strength of clay soils can be found in the ICE manual of geotechnical engineering (2012), Volume I, Chapter 17 [3].

4.3.1.5 Mixed soils

COMMENTARY ON 4.3.1.5

Some deposits (especially glacial deposits) can comprise a mixture of fine and coarse soils, e.g. sandy clays and clayey sands. The behaviour of mixed soils is typically intermediate between that of coarse and fine soils.

For mixed soils with clay fraction less than 50% (plasticity index less than 30% or liquid limit less than 60%), $\phi'_{cv,k}$ may, in the absence of reliable test data, be estimated from *Drained shear strength parameters for analysis of landslides* [15].

4.3.1.6 Soil stiffness

COMMENTARY ON 4.3.1.6

Young's modulus of elasticity of an isotropic soil (E) is related to its shear modulus (G) by:

$$E = 2G(1 + \nu) \quad (10)$$

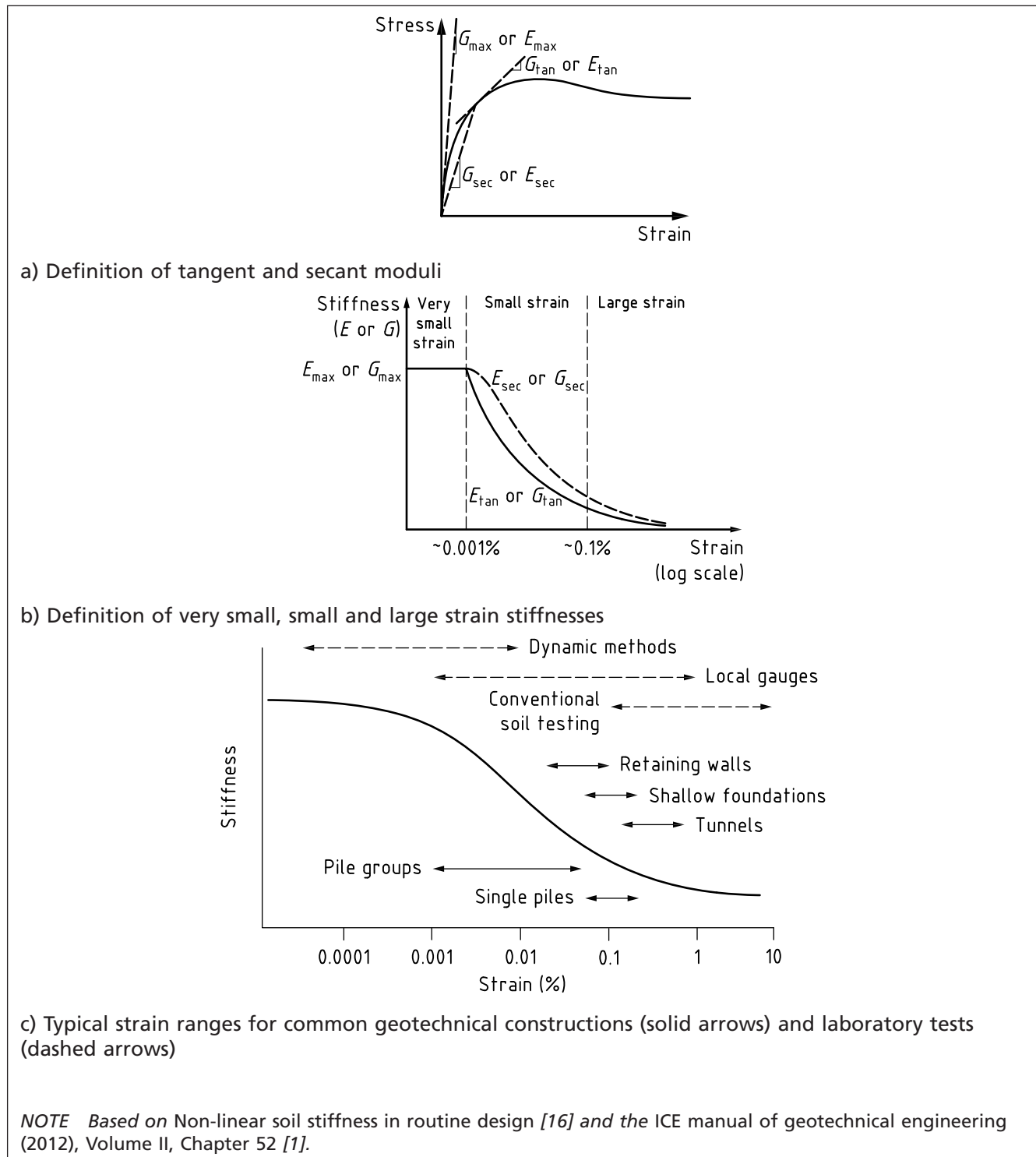
where:

ν is the soil's Poisson's ratio.

Stiffness parameters for a soil depend on the level of strain (axial ε or engineering shear strain γ) applied to the soil, as illustrated in Figure 3:

- at very small strains (ε or $\gamma \leq \sim 0.001\%$), the soil's moduli of elasticity (E and G) reach their maximum values ($E_{\max}$ and $G_{\max}$), also known as "very-small-strain" values; $E_{\max}$ and $G_{\max}$ are normally measured using dynamic methods, such as laboratory tests using bender-elements or field tests using seismic methods;
- at small strains ($0.001\% \leq \varepsilon$ or $\gamma \leq \sim 0.1\%$), E and G decrease rapidly with increasing strain, as shown in Figure 3; their values are measured using advanced methods, such as laboratory tests with local gauges;
- tangent values of small-strain stiffness ($E_{\tan}$ and $G_{\tan}$) are commonly used in numerical methods of design;
- at large strains (ε or $\gamma > \sim 0.1\%$), E and G decrease less rapidly with increasing strain and are commonly taken to be constant in value; those values are measured using conventional laboratory testing;
- secant values of large-strain stiffness ($E_{\sec}$ and $G_{\sec}$) are commonly used in routine methods of design;
- soil stiffness parameters are not normally isotropic. Simple isotropic models are to be used with caution, especially if their adequacy has not been demonstrated by back analysis. Depending on the soil's deposition history, different values of stiffness might be appropriate for vertical strains (E_v) compared to horizontal strains (E_h) and for shearing in different directions ($G_{h/v}$, $G_{v/h}$).

Figure 3 Stiffness parameters for non-linear soil



4.3.1.6.1 The difference between the direction of loading and the direction of measurement of soil stiffness should be taken into account in the assessment of soil stiffness.

4.3.1.6.2 The secant shear modulus of a soil, G_{sec} , may be estimated from (see also *Stiffness of sands through a laboratory database* [17]):

$$\frac{G_{\text{sec}}}{G_{\text{max}}} = \left[1 + \left(\frac{\gamma - \gamma_e}{\gamma_{\text{ref}}} \right)^m \right]^{-1} \leq 1 \quad (11)$$

where:

- G_{max} is the soil's very-small-strain shear modulus;
- γ is the engineering shear strain in the soil;
- γ_e is the elastic threshold strain beyond which shear modulus falls below its maximum value;
- γ_{ref} is a reference value of engineering shear strain (at which $G_{\text{sec}}/G_{\text{max}} = 0.5$); and
- m is a coefficient that depends on soil type.

4.3.1.6.3 In the absence of reliable test results, the values of the parameters in equation (11) may be taken from Table 3.

Table 3 Values of parameters for use with equation (11)

Soil type	Parameter			Reference
	γ_{ref} %	m	γ_e %	
Sand	0.02–0.1 (0.044 ^{A)})	0.88	0.02% + 0.012 γ_{ref}	Oztoprak and Bolton [18]
Clays and silts	0.0022 I_p ^{B)}	0.736 ± 0.122 ^{C)}	0 (assumed)	Vardanega and Bolton [19]

^{A)} Mean value.

^{B)} I_p is the soil's plasticity index.

^{C)} ± value indicates standard error.

4.3.1.6.4 In the absence of reliable test results, the very-small-strain shear modulus of a soil G_{max} may be estimated from (see *Non-linear soil stillness in routine design* [16] and *Stiffness at small strain: research and practice* [20]):

$$\frac{G_{\text{max}}}{p_{\text{ref}}} = \frac{k_1}{(1+e)^{k_2}} \left(\frac{p'}{p_{\text{ref}}} \right)^{k_3} \quad (12)$$

where:

- e is the soil's voids ratio;
- p' is the mean effective stress in the soil;
- p_{ref} is 100 kPa; and
- k_1 , k_2 , and k_3 are coefficients that depend on soil type.

4.3.1.6.5 In the absence of reliable test results, the values of the parameters in equation (12) may be taken from Table 4.

Table 4 Values of parameters for use with equation (12)

Soil type	Parameter				Reference
	k_1	k_2	k_3	p_{ref}	
Fine soil	2 100 ^{A)}	0	0.6–0.8 ^{A)}	1 kPa	Viggianni and Atkinson [21]
Sand	370–5 760 ^{B)}	3	0.49–0.86 ^{C)}	100 kPa	Oztoprak and Bolton [18]
Clays and silts	20 000 ±5 000	2.4	0.5	1 kPa	Vardanega and Bolton [19]

^{A)} Depends on the soil's plasticity index, I_p .

^{B)} Decreasing with strain.

^{C)} Increasing with strain.

4.3.2 Rocks and rock masses

COMMENTARY ON 4.3.2

The engineering properties of rock relevant in design are controlled by the extent and orientation of the bedding planes and joints within the rock mass, together with the water pressures on the discontinuity planes. The site investigation needs to establish the strength and orientation of the discontinuity planes.

Weak rocks, particularly weakly cemented sandstones, fissured shales and chalk, are often difficult materials to sample and test.

4.3.2.1 The identification and classification of rock should conform to BS EN ISO 14689-1.

4.3.2.2 Rock properties should be determined in accordance with BS EN 1997-2 and BS 5930, as well as BS EN 1997-1:2004+A1:2013, 3.3.2, 3.3.8 and 3.3.9.

4.3.2.3 Characteristic rock parameters for intact rock should be selected in accordance with BS EN 1997-1, based on the results of field and laboratory tests, complemented by well-established experience.

4.3.2.4 Design parameters for the rock mass should take into account the properties of the intact rock and any discontinuities. See BS EN 1997-1:2004+A1:2013, 3.3.8.

4.3.2.5 The following non-destructive tests may be used to determine rock mineralogy and composition in order to predict the rock's performance during excavation (in particular, if it will slurry or smear rather than be broken up into smaller pieces):

- microscope;
- X-ray computerized tomography; and
- spectroscopy.

NOTE 1 Guidance on rock description in engineering practice can be found in Soil and rock description in engineering practice [9].

NOTE 2 Information about the behaviour of rocks can be found in the ICE manual of geotechnical engineering (2012), Volume I, Chapter 18 [3].

NOTE 3 Information about mudrocks, clay, and pyrite (and their issues) can be found in the ICE manual of geotechnical engineering (2012), Volume I, Chapter 36 [3].

4.3.3 Fill

COMMENTARY ON 4.3.3

The term “fill” refers to artificially deposited material, for example, in an excavation or as ground made by human activity. These materials are also termed “artificial ground”.

“Non-engineered” fill is material that is dumped with little control and in deep lifts. It is often poorly compacted, and thus in a loose state, and has varying geotechnical properties, both horizontally and vertically. Non-engineered fill is commonly referred to as “made ground”.

“Engineered” fill is material that is placed with some degree of control to ensure that its geotechnical properties conform to a predetermined specification. Engineered fill is commonly referred to as just “fill”.

On geological maps, “made ground” refers to material placed above and “fill” to material placed below original ground level. On recent British Geological Survey (BGS) maps, these terms have been altered to “made up ground” and “infilled ground”.

4.3.3.1 All materials intended to be placed behind earth retaining structures should be properly investigated and classified.

4.3.3.2 Non-engineered fill, such as industrial, chemical, and domestic wastes, should not be placed behind earth retaining structures.

4.3.3.3 Engineered fill comprising selected coarse granular soils, such as well-graded small rockfills, gravels, and sands, may be placed behind earth retaining structures.

4.3.3.4 Engineered fill should be appropriate to the intended application. The fill should be classified and an earthworks specification provided detailing acceptability criteria, compliance testing, and compaction requirements. The general specification of earthworks fill should conform to BS 6031.

NOTE 1 Guidance on the description of made ground can be found in Soil and rock description in engineering practice, Chapter 14 [9].

NOTE 2 Information about non-engineered fills can be found in the ICE manual of geotechnical engineering (2012), Volume I, Chapter 34 [3].

NOTE 3 Information about fill formation and deposits, covering opencast mining backfill, colliery spoil, pulverized fly ash, industrial and chemical wastes, urban fill, domestic refuse, infilled docks, pits, and quarries, and hydraulic fill, can be found in BRE Report 424 (2nd edition), Chapter 2 [22].

4.3.4 Earthworks

The properties of earthworks should be determined in accordance with BS 6031.

4.3.5 Groundwater

4.3.5.1 Groundwater pressures should be determined by considering hydrological, hydrogeological and environmental information.

4.3.5.2 To conform to BS EN 1997-1:2004+A1:2013, 2.4.6.1(6)P, design values of groundwater pressure at the serviceability limit state should be the most unfavourable values that could occur during normal circumstances.

4.3.5.3 To conform to BS EN 1997-1:2004+A1:2013, 2.4.6.1(6)P, design values of groundwater pressure at the ultimate limit state should be the most unfavourable values that could occur during the design lifetime of the structure.

NOTE The relationship between characteristic and design water pressures can be determined by applying a geometrical margin.

4.3.5.4 If suitable statistical data are available, then design values of groundwater pressure at the serviceability limit state should be chosen with a return period at least equal to the duration of the design situation, and design values at the ultimate limit state should be chosen such that there is a 1% probability that they are exceeded during the design situation.

4.3.5.5 Where groundwater pressures are not hydrostatic, the design should take into account:

- the worst credible combination of heterogeneity and anisotropy of permeability;
- effects of layering, fissuring and other heterogeneity;
- any geometrical features that could cause pressures to concentrate (such as in corners of excavations).

4.3.5.6 Long-term changes in groundwater that are likely to occur during the design working life of the structure (including those due to climate change and rising groundwater) should be taken into account.

4.3.5.7 Increased groundwater pressures owing to burst pipes and other failures of engineered systems should be classified as accidental actions if the event that causes the increase in groundwater pressure is unlikely to occur during the design working life of the structure.

4.3.5.8 The design of an earth retaining structure should be based on the most adverse water pressure conditions that can be anticipated.

NOTE Guidance on the selection of water tables and seepage forces can be found in CIRIA Report C580 [N3].

4.3.5.9 Design water pressures should take into account the effect of tides on water levels in the ground.

NOTE Guidance on tides and water level variations can be found in BS 6349-1-3.

4.3.5.10 If the equilibrium level of the water table is well defined and measures are taken to prevent it changing during heavy rain or flood, the design water pressures can be calculated from the position of the equilibrium water table, making due allowance for possible seasonal variations, otherwise the most adverse water pressure conditions that can be anticipated should be used in design.

4.3.5.11 Equilibrium water levels in fine soils should be determined from piezometric readings taken over an adequate length of time.

4.3.5.12 Allowance should be made in undrained (i.e. total stress) analyses for water pressures due to the temporary filling of cracks in fine soils.

4.3.5.13 Water pressures used in drained (i.e. effective stress) analyses should be determined for the groundwater regime in the vicinity of the structure.

4.3.5.14 Where a difference in water pressures exists on opposite sides of an earth retaining structure, allowance should be made for seepage around the wall. Where layers of markedly different permeability exist, the water levels relevant to each permeable stratum should be taken into account.

4.3.5.15 The distribution of pore water pressures may be determined from a flow net, provided it adequately represents the hydraulic and permeability conditions in the vicinity of the structure.