

BS 8004:2015+A1:2020



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Code of Practice for foundations

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Contents

	Page
Foreword	iii
1 Scope	1
2 Normative references	1
3 Terms, definitions and symbols	5
4 General rules	6
4.1 Choice and design of foundation	6
4.2 Basis of geotechnical design	7
4.3 Materials	12
<i>Figure 1 — Suggested values for characteristic weight density of soils above the groundwater table</i>	13
<i>Figure 2 — Suggested values for characteristic weight density of soils below the groundwater table</i>	14
<i>Table 1 — Values of φ'_{ang}, φ'_{PSD} and φ'_{dil} to obtain values of $\varphi'_{\text{pk,k}}$ and $\varphi'_{\text{cv,k}}$ for siliceous sands and gravels with fines content not exceeding 15%</i>	16
<i>Table 2 — Values of $\varphi'_{\text{cv,k}}$ for fine soils from plasticity index</i>	18
<i>Figure 3 — Stiffness parameters for non-linear soil</i>	20
<i>Table 3 — Values of parameters for use with equation (12)</i>	21
<i>Table 4 — Values of parameters for use with equation (13)</i>	21
4.4 Durability	26
<i>Table 5 — Use classes relevant to timber in foundations</i>	27
4.5 Geotechnical analysis	27
4.6 Ultimate limit states	27
4.7 Serviceability limit states	29
4.8 Structural design	29
4.9 Execution	29
4.10 Testing	30
4.11 Supervision, monitoring, and maintenance	31
4.12 Reporting	31
5 Spread foundations	33
5.1 Choice and design of spread foundations	33
<i>Table 6 — Some key features of spread foundations</i>	33
5.2 Actions and design situations	35
5.3 Design considerations	35
5.4 Calculation models	37
5.5 Materials	42
5.6 Durability	42
5.7 Ultimate limit state design	42
5.8 Serviceability limit state design	43
5.9 Structural design	43
5.10 Execution	43
5.11 Testing	43
5.12 Supervision, monitoring, and maintenance	44
5.13 Reporting	44
6 Pile foundations	44
6.1 Choice and design of pile foundations	44
<i>Table 7 — Classification of piles according to ground disturbance caused by installation</i>	44
6.2 Actions and design situations	46
6.3 Design considerations	46
6.4 Calculation models	48
<i>Table 8 — Suggested values of K_s for piles installed in coarse silica soils</i>	50

	<i>Table 9 — Suggested values of k_8 for piles installed in coarse soils</i>	51
	<i>Table 10 — Suggested values of k_2 for piles installed in fine soil</i>	54
	<i>Table 11 — Values of the empirical coefficients c_s and $c_{b,0.1}$ according to soil and pile type</i>	56
	<i>Table 12 — Values of the empirical coefficients n_s and $n_{b,0.1}$ according to soil and pile type</i>	57
	<i>Figure 4 — Calculation model for downdrag</i>	61
	<i>Table 13 — Suggested values of the coefficients k_1 and k_4 for piles installed in rocks</i>	63
6.5	Materials	66
6.6	Durability	68
6.7	Ultimate limit state design	68
6.8	Serviceability limit state design	73
6.9	Structural design	74
	<i>Table 14 — Design pile diameter for cast-in-place piles without permanent casing</i>	76
6.10	Execution	77
6.11	Testing	79
6.12	Supervision, monitoring, and maintenance	81
6.13	Reporting	81
Annex A	(normative) Helical steel pile foundations	83
Annex B	(normative) Underpinning	87
Annex C	(informative) Specific Formations	91
Annex D	(informative) Archaeological finds	93
	Bibliography	94

Summary of pages

This document comprises a front cover, and inside front cover, pages i to iv, pages 1 to 101, an inside back cover and a back cover.

Foreword

Publishing information

This British Standard is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 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

BS 8004:2015+A1:2020 supersedes BS 8004:2015, which is withdrawn.

Relationship with other publications

BS 8004 gives non-contradictory, complementary information for use with [BS EN 1997](#) and its 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 foundations according to limit state principles using partial factors;
- guidance is given on the selection of design parameters for soils;
- guidance is given on the calculation of ultimate bearing resistance of shallow foundations;
- guidance is given on the design of pile foundations by calculation and by testing;
- the revised text reflects advances in foundation technology over the past 30 years.

Text introduced by or altered by Amendment No. 1 is indicated in the text by tags **A1** and **A1**. Minor editorial corrections are not tagged.

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 foundations for the normal range of buildings and engineering structures. 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 foundations; [Clause 5](#) and [Clause 6](#) give specific recommendations for the design and construction of spread foundations and pile foundations (respectively).

[Annex A](#) gives specific recommendations for the design and construction of helical steel piles.

[Annex B](#) gives specific recommendations for the design and construction of underpinning.

[Annex C](#) gives information about specific geological formations encountered in the UK.

[Annex D](#) gives information about the UK Government's policy regarding archaeological finds.

NOTE 1 This standard does not cover the design and construction of earthworks, for which see [BS 6031](#).

NOTE 2 This standard does not cover the design and construction of earth retaining structures, for which see [BS 8002](#).

NOTE 3 This standard does not cover the design and construction of maritime works, for which see [BS 6349](#).

NOTE 4 For non-industrial structures of not more than four storeys, see [BS 8103-1](#).

NOTE 5 This standard does not cover the design and construction of foundations for reciprocating machinery.

NOTE 6 This standard does not cover the design and construction of offshore foundations, for which see BS EN ISO 19901-4.

2 Normative references

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

[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 1852-1](#), *Plastics piping systems for non-pressure underground drainage and sewerage – Polypropylene (PP) – Part 1: Specifications for pipes, fittings and the system*

[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 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](#), *Code of practice for earthworks*

BS 6349 (all parts), *Maritime works*

[BS 8006-1:2010](#), *Code of practice for strengthened/reinforced soils and other fills*

[BS 8002](#), *Code of practice for earth retaining structures*

[BS 8081](#), *Code of practice for ground anchors*

[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 8500-2](#), *Concrete – Complementary British Standard to BS EN 206-1 – Part 2: Specification for constituent materials and concrete¹⁾*

[BS 10175](#), *Code of practice on investigation of potentially contaminated sites*

BS EN 206:2013, *Concrete – Specification, performance, production and conformity*

[BS EN 295](#), *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*

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 1090 (all parts), *Execution of steel structures and aluminium structures*

BS EN 1401-1, *Plastic piping systems for non-pressure underground drainage and sewerage – Unplasticized poly(vinyl chloride) (PVC-U) – Part 1: Specifications for pipes, fittings and the system*

BS EN 1536, *Execution of special geotechnical works – Bored piles²⁾*

¹⁾ Informative reference is made to BS 8500-2:2015.

²⁾ Informative reference is made to BS EN 1536:2010+A1:2015.

BS EN 1852-1, *Plastics piping systems for non-pressure 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 (all parts), *Eurocode 1: Actions on structures*³⁾

BS EN 1992 (all parts), *Eurocode 2: Design of concrete structures*⁴⁾

BS EN 1993 (all parts), *Eurocode 3: Design of steel structures*⁵⁾

BS EN 1995 (all parts), *Eurocode 5: Design of timber structures*⁶⁾

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 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 (incorporating corrigendum 2010)*

[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 10219](#), *Cold formed welded structural hollow sections of non-alloy and fine grain steels*

[BS EN 10248](#), *Hot rolled sheet piling of non alloy steels*

[BS EN 10249](#), *Cold formed sheet piling of non alloy steels*

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 12699, *Execution of special geotechnical work – Displacement piles*⁷⁾

BS EN 12715, *Execution of special geotechnical works – Grouting*

BS EN 12716, *Execution of special geotechnical works – Jet grouting*

BS EN 12794, *Precast concrete products – Foundation piles*

BS EN 13670, *Execution of concrete structures*

BS EN 14199:2015, *Execution of special geotechnical works – Micropiles*

BS EN 14227 (all parts), *Hydraulically bound mixtures – Specifications*

BS EN 14679:2005, *Execution of special geotechnical works – Deep mixing*

BS EN 14731:2005, *Execution of special geotechnical works – Ground treatment by deep vibration*

BS EN 15237:2007, *Execution of special geotechnical works – Vertical drainage*

³⁾ Specific references are made to the following part: BS EN 1991-2:2003, *Eurocode 1: Actions on structures – Part 2: Traffic loads on bridges*.

⁴⁾ Specific references are made to the following part: BS EN 1992-1-1:2004+A1:2014, *Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings*.

⁵⁾ Specific references are made to the following parts:

- BS EN 1993-1-1:2005, *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*.

⁶⁾ Specific references are made to the following part: BS EN 1995-1-1:2004, *Eurocode 5: Design of timber structures – Part 1-1: General – Common rules and rules for buildings*.

⁷⁾ Informative reference is made to BS EN 12699:2001.

[BS EN 16228](#), *Drilling and foundation equipment – Safety*

BS EN ISO 13793, *Thermal performance of buildings – Thermal design of foundations to avoid frost heave*

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*⁸⁾

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

prEN ISO 22476-13, *Geotechnical investigation and testing – Field testing – Part 13: Plate loading test*⁹⁾

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

[BS ISO 5667-11](#), *BS 6068-6.11: Water quality – Sampling – Part 11: Guidance on sampling of groundwaters*

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

NA to BS EN 1992-1-1, *UK National Annex to Eurocode 2 – Design of concrete structures – Part 1-1: General rules and rules for buildings*¹⁰⁾

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 1993-1-1, *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*

NA+A1:2014 to BS EN 1997-1:2004+A1:2013, *UK National Annex to Eurocode 7 – Geotechnical design – Part 1: General rules*

NA+A1:2014 to BS EN 1997-1:2004+A1:2013, *UK National Annex to Eurocode 7 – Geotechnical design – Part 1: General rules*

[PAS 8811](#), *Code of practice for temporary works – Client procedures*

[PAS 8812](#), *Guide to the application of European Standards in temporary works design*

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

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

ASTM D7949-14, *Standard test methods for thermal integrity profiling of concrete deep foundations*¹¹⁾

Other publications

[N1] 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.

[N2] LORD, J.A., CLAYTON, C.R.I., and MORTIMORE, R.N. *Engineering in chalk (CIRIA Report C574)*. London: CIRIA, 2002. ISBN 0-86017-574-X.

⁸⁾ Informative reference is made to BS EN ISO 14688-2:2004+A1:2003.

⁹⁾ In preparation.

¹⁰⁾ Informative reference is made to NA to BS EN 1992-1-1:2004.

¹¹⁾ Available from ASTM International, www.astm.org (last viewed 25/6/15).

[N3] 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.

3 Terms, definitions and symbols

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 low-rise building/housing

building of not more than three storeys above ground intended for domestic occupation and of traditional masonry construction

NOTE For example, detached, semi-detached, and terraced housing or flat. Also includes certain single-storey, non-residential buildings.

3.2 micropiles

drilled piles which have a diameter smaller than 300 mm

[SOURCE: BS EN 14199:2015, 3.1]

3.3 undrained shear strength of fine soils (c_u)

[SOURCE: BS EN ISO 14688-2:2004+A1:2013, Table 5]

3.3.1 extremely low

$$c_u < 10 \text{ kPa}$$

3.3.2 very low

$$c_u = 10\text{--}20 \text{ kPa}$$

3.3.3 low

$$c_u = 20\text{--}40 \text{ kPa}$$

3.3.4 medium

$$c_u = 40\text{--}75 \text{ kPa}$$

3.3.5 high

$$c_u = 75\text{--}150 \text{ kPa}$$

3.3.6 very high

$$c_u = 150\text{--}300 \text{ kPa}$$

3.3.7 extremely high

$$c_u > 300 \text{ kPa}$$

3.4 working platform

temporary structure that provides a foundation for construction plant

4 General rules

4.1 Choice and design of foundation

4.1.1 General

- 4.1.1.1** The design of foundations should conform to BS EN 1997-1 and this [Clause \(4\)](#).

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

NOTE 2 Guidance on the selection of a suitable foundation type can be found in the ICE manual of geotechnical engineering (2012), Volume I, Chapter 9 [2] and Volume II, Chapter 52 [1].

- 4.1.1.2** The design of maritime works should conform to [BS 6349](#).

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

4.1.2 Spread foundations

- 4.1.2.1** The design of spread foundations should conform to [4.1.1.1](#) and [Clause 5](#).

NOTE Spread foundations are generally suitable in, but not limited to, the following design situations:

- where an adequate bearing stratum occurs at shallow depth (typically less than 2 m deep);
- on dense (or denser) coarse soils above the water table;
- on medium strength (or stronger) fine soils.

- 4.1.2.2** Spread foundations should not be placed on non-engineered fill unless such use can be justified on the basis of a thorough ground investigation and detailed design. Spread foundations should generally not be placed on engineered fill unless that fill is designed for the use of spread foundations.

4.1.3 Pile foundations

- 4.1.3.1** The design of pile foundations should conform to [4.1.1.1](#) and [Clause 6](#).

NOTE Pile foundations are generally suitable in, but not limited to, the following design situations:

- on compressible strata overlying bedrock;
- on compressible strata overlying coarse soils of adequate density, there being no other beds of greater compressibility below the coarse soils;
- where the strata consist of fine soils of great thickness capable of supporting the piles by friction;
- where there is a need to minimize movements of a structure owing to swelling or shrinkage of surface soils; and
- where the addition of a foundation load would cause instability of the existing ground (e.g. at the crest of an existing slope).

- 4.1.3.2** Deep foundations, such as piles, should be considered when no adequate bearing stratum exists at shallow depths to permit economic construction of spread foundations.

- 4.1.3.3** The design of helical steel pile foundations should conform to [Annex A](#).

4.1.4 Underpinning

The design of underpinning should conform to [4.1.1.1](#) and [Annex B](#).

NOTE 1 Underpinning is typically used for, but not limited to, the following design situations:

- to rectify distress that a structure has already suffered;

- to extend foundations downwards to enable building and civil engineering works to be carried out; and
- to provide adequate resistance to increased loading on an existing structure.

NOTE 2 Guidance on the use of underpinning can be found in the ICE manual of geotechnical engineering (2012), Volume II, Chapter 83 [1].

4.1.5 Piled rafts

There are two different types of piled raft in common practice: raft-enhanced pile groups and pile-enhanced rafts.

- 4.1.5.1** The design of piled rafts should conform to [4.1.1.1](#) and [Clause 5](#) and [Clause 6](#).

NOTE 1 Piled rafts are typically used for, but not limited to, the following design situations:

- to minimize total, and particularly differential, foundation settlement;
- to reduce bending moments and shear forces in unpiled rafts; and
- to reduce the thickness of a raft foundation.

NOTE 2 Guidance on the use of piled rafts can be found in the ICE manual of geotechnical engineering (2012), Volume II, Chapter 56 [1].

- 4.1.5.2** The design of raft-enhanced pile groups should ensure that stresses within both the piles and the raft do not exceed the elastic range of behaviour.

- 4.1.5.3** The design of pile-enhanced rafts should ensure that all of the piles mobilise their ultimate resistance before the raft reaches its ultimate resistance.

4.1.6 Piled embankments

- 4.1.6.1** The design of piles used in piled embankments should conform to [4.1.1.1](#) and [Clause 6](#).

NOTE Piled embankments are typically used for, but not limited to, the following design situations:

- to support infrastructure over low strength ground (e.g. alluvium);
- to support infrastructure over compressible ground (e.g. loose fill);
- to support infrastructure over collapsing ground (e.g. loess and karst geology); and
- to support infrastructure over unstable areas (e.g. land prone to mining subsidence).

- 4.1.6.2** The design of embankments should conform to [BS 6031](#).

- 4.1.6.3** The design of basal reinforcement to piled embankments should conform to [BS 8006-1:2010](#), **8.3**.

4.2 Basis of geotechnical design

NOTE Attention is drawn to The Construction (Design and Management) Regulations 2015 [3], with regards to health and safety requirements for construction works, in particular:

- Regulation 9, duties of designers;
- Regulation 11, duties of the principal designer in relation to 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 foundations should conform to BS EN 1997-2:2007, **B.3**, and this Clause.
- 4.2.1.1.7** The number of investigation points should be sufficient to establish ground conditions, and any variability in those conditions, in the vicinity of the foundation.
- 4.2.1.1.8** For low-rise buildings, the number of investigation points undertaken (n) should satisfy the following, unless the ground conditions can be shown to be sufficiently uniform to justify a greater spacing:

$$n \geq \begin{cases} 3 & \text{for } A \leq 300\text{m}^2 \\ A/100\text{ m}^2 & \text{for } A > 300\text{m}^2 \end{cases} \quad (1)$$

where:

A is the plan area of each building's footprint.

- 4.2.1.1.9** Where a development involves construction of several buildings, equation (1) may be applied to the aggregate plan area of the buildings' footprints, provided the ground conditions can be shown to be sufficiently uniform.
- 4.2.1.1.10** For high-rise buildings and industrial structures, the number of investigation points undertaken should conform to BS EN 1997-2:2007, **B.3**.
- 4.2.1.1.11** For low-rise buildings, the depth of investigation below the planned base of the foundation (Z_a) should satisfy the following minimum requirements:

$$Z_a \geq \begin{cases} 2b_F \\ 3\text{m} \end{cases} \quad (2)$$

where:

b_F is the smaller side length of the foundation (on plan).

- 4.2.1.1.12** For high-rise buildings and industrial structures, the depth of investigation should conform to the minimum requirements of BS EN 1997-2:2007, **B.3**, namely:

$$Z_a \geq \begin{cases} 3b_F \\ 6\text{m} \end{cases} \quad (3)$$

- 4.2.1.1.13** Where the base of the foundation is located on or near bedrock, the depth of investigation may be reduced.
- 4.2.1.1.14** The presence of trees and large shrubs should be noted 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 [2] and in the NHBC Design Guide NF21, Efficient design of piled foundations for low rise housing (2010), Section 4: Site investigation [4].

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 foundations should include:

- the conditions given in BS EN 1997-1:2004+A1:2013, **6.3**;
- collapse settlement;
- building within the zone of influence of buried highwalls (at the edge of opencast mining);
- building over landfill;
- the influence of global ground movements on foundation performance; and
- all other conditions specific to the site that can reasonably be foreseen.

4.2.2.3 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.**4.2.2.4** Design water levels should be compatible with the drainage provisions.

NOTE Information about exclusion zones around buried highwalls can be found in BRE Report 424 [5].

4.2.3 Design considerations**COMMENTARY ON 4.2.3**

Design and construction considerations for foundations are given throughout BS EN 1997-1. The design considerations given in this Clause are more specific examples of the issues that can affect the performance of a foundation.

4.2.3.1 General

The design of foundations should consider:

- the design considerations given in BS EN 1997-1:2004+A1:2013, **6.4**;
- the possibility of weak layers below the proposed foundation level leading to greater settlement of the foundation than would occur in their absence;
- the possibility of shear failure of the ground supporting the foundation owing to the presence of cuttings, excavations, or sloping ground;
- the possibility of inclined or jointed strata in which the bedding or joint planes dip towards an excavation or natural depression causing stability problems due to failure along bedding planes or joints;
- the possibility of settlement of adjacent structures caused during or after construction of the foundations;
- the effect on the groundwater regime during and after construction;
- the execution (i.e. construction or installation) of the foundation; and
- global ground movements (e.g. due to bulk excavation or filling, water table changes, etc.) that can cause foundation deformations, additional to those induced by superstructure loads, and/or additional forces in the foundation or superstructure.

NOTE Global ground movements can be horizontal or vertical depending on the design situation.

4.2.3.2 Drainage**COMMENTARY ON 4.2.3.2**

Provision of suitable drainage is vital to ensure the acceptable performance of a foundation. 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 water pressures during construction in case they have harmful effects upon the foundations; and
- instability of slopes.

4.2.3.2.2 Surface water drains should be constructed using one of the types of pipe listed in [4.3.10](#).

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

4.2.3.2.4 Drainage systems should be designed with positive outfalls to prevent ponding and include provisions of suitable discharge outfalls or soakaways.

4.2.3.2.5 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.

NOTE 1 Guidance on surface water control can be found in *Groundwater lowering in construction* [6], *Construction dewatering and groundwater control* [7], and *Groundwater control: design and practice* [8].

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 design of foundations subject to cyclic loading should consider the following:

- 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

Foundations 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 Foundations 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 [9].

4.2.3.5 Environmental considerations

The design of foundations should consider:

- 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);
- the use of ground improvement; and
- the carbon footprint of the construction and the use of the structure.

4.2.3.6 Ground improvement

COMMENTARY ON 4.2.3.6

Ground improvement is the modification of ground properties obtained by binding or densifying the ground or creating inclusions in the ground. Ground improvement involves the enhancement of ground properties, principally by strengthening or stiffening processes and compaction or densification mechanisms, to achieve a specific geotechnical performance (see ICE manual of geotechnical engineering, Volume I [2]).

Ground improvement includes any method by which natural or disturbed ground has its geotechnical performance altered.

Ground improvement covers many methods of ground treatment, including: modification, chemical alteration, reinforcement with steel or geosynthetics, strengthening by drainage, densification by vibration or consolidation, void filling, settlement or compensation grouting (see Contributions to Géotechnique 1948–2008 [10]).

Ground improvement techniques can be used to alter ground strength, stiffness, or permeability. Common applications include methods to enhance bearing resistance, control post-construction settlements, increase or decrease ground permeability, improve ground stability, generate controlled ground displacement, and mitigate the risk of liquefaction.

4.2.3.6.1 The design of ground improvement by deep mixing should conform to BS EN 14679:2005, Clause 7.

4.2.3.6.2 The design of ground improvement by deep vibration should conform to BS EN 14731:2005, Clause 7.

4.2.3.6.3 The design of ground improvement by vertical drainage should conform to BS EN 15237:2007, Clause 7.

NOTE 1 Comprehensive guidance on the design and execution of the most common forms of ground improvement can be found in Ground Improvement [11].

NOTE 2 Information about the role of ground improvement can be found in the ICE manual of geotechnical engineering (2012), Volume I, Chapter 25 [2].

NOTE 3 Guidance on vibrocompaction and vibro stone columns, vibro concrete columns, and dynamic compaction can be found in the ICE manual of geotechnical engineering (2012), Volume II, Chapters 59 and 84 [1].

NOTE 4 Guidance on a range of ground improvement techniques can be found in CIRIA Reports C572 [12] and C573 [13].

NOTE 5 Guidance on grouting for ground engineering (including permeation, rock grouting, hydrofracture, ground compaction, jet grouting, and compensation grouting) can be found in CIRIA Report C514 [14].

NOTE 6 Guidance on soil mixing can be found in the BRE Design Guide to soft soil stabilisation [15].

NOTE 7 Information about vibro stone columns can be found in BRE Report BR 391 [16].

NOTE 8 Information about the design of vibrocompaction/vibroflotation and vertical band drains can be found in the Institution of Civil Engineers' Specification for ground treatment [17].

NOTE 9 Guidance on the design, construction and control of rigid inclusion ground improvements can be found in the recommendations of the ASIRI National Project [18].

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 C](#).

4.3.1 Soils

4.3.1.1 General

COMMENTARY ON 4.3.1.1

The design of foundations 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 foundations 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 Guidance on soil description can be found in Soil and rock description in engineering practice [19].

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 [2].

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 [2].

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*

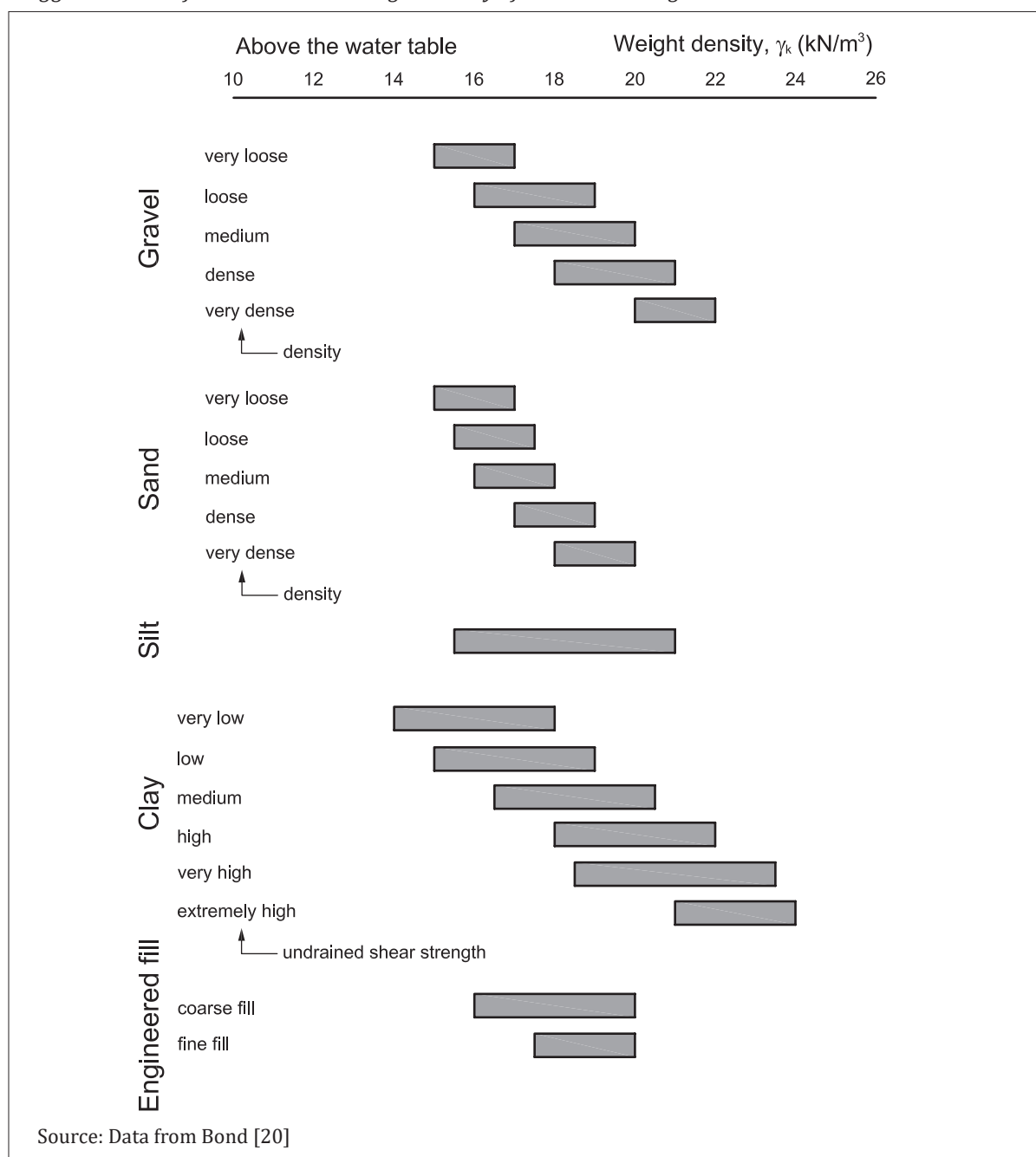
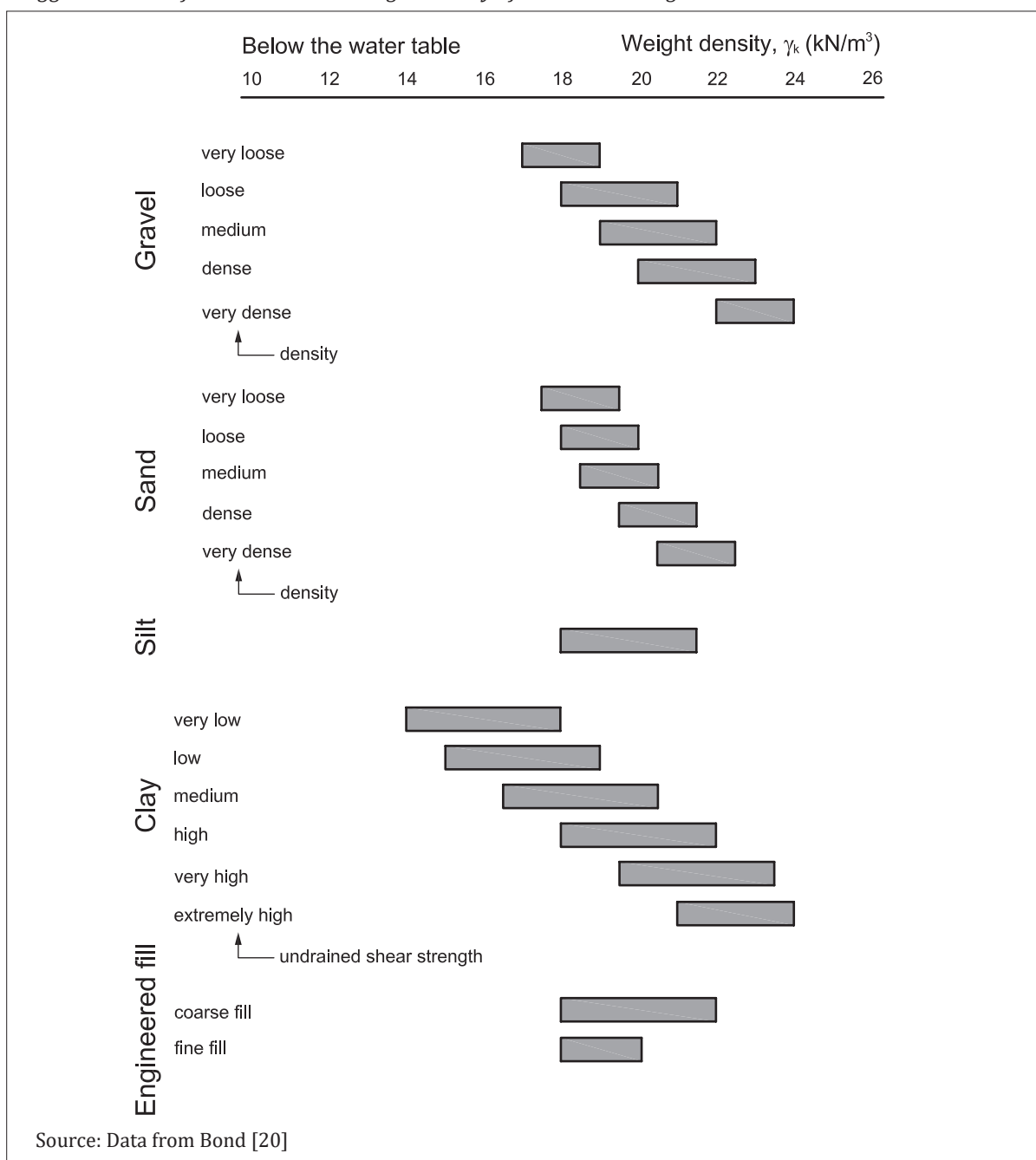


Figure 2 — Suggested values for characteristic weight density of soils below the groundwater table

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:

$$\phi'_{cv,k} = 30^\circ + \phi'_{ang} + \phi'_{PSD} \quad (4)$$

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 ($\varphi'_{pk,k}$) may be estimated from:

$$\varphi'_{pk,k} = \varphi'_{cv,k} + \varphi'_{dil} \quad (5)$$

where:

φ'_{dil} is contribution to $\varphi'_{pk,k}$ 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:

$$\varphi'_{dil} = n l_R = n [l_D \ln(\sigma_c / \sigma'_f) - 1] \quad (6)$$

where:

- n is 3 for triaxial strain or 5 for plane strain;
- l_R is the soil's relative dilatancy index;
- l_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 the mean effective stress in the soil at peak strength.

NOTE 1 The value of φ'_{dil} derived by equation (6) is in angular units of degrees.

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* [21]).
- 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 $\varphi'_{pk,k}$ and $\varphi'_{cv,k}$ 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	$\varphi'_{ang} = 0^\circ$
		Sub-angular to angular	$\varphi'_{ang} = 2^\circ$
		Very angular to angular	$\varphi'_{ang} = 4^\circ$
Uniformity coefficient, C_u , ^{B)}	Soil grading	$C_u < 2$ (evenly graded)	$\varphi'_{PSD} = 0^\circ$
		$2 \leq C_u < 6$ (evenly graded)	$\varphi'_{PSD} = 2^\circ$
		$C_u \geq 6$ (medium to multi graded)	$\varphi'_{PSD} = 4^\circ$
		High C_u (gap graded), with C_u of fines < 2 ^{E)}	$\varphi'_{PSD} = 0^\circ$
		High C_u (gap graded), with $2 \leq C_u$ of fines < 6 ^{E)}	$\varphi'_{PSD} = 2^\circ$
Density index, I_D , ^{C)}	Standard penetration test blow count, corrected for energy rating and overburden pressure $(N_1)_{60}$	$I_D = 0\%$	$\varphi'_{dil} = 0^\circ$
		$I_D = 25\%$	$\varphi'_{dil} = 0^\circ$
		$I_D = 50\%$	$\varphi'_{dil} = 3^\circ$
		$I_D = 75\%$	$\varphi'_{dil} = 6^\circ$
		$I_D = 100\%$	$\varphi'_{dil} = 9^\circ$

^{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* [21].

^{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;
- desiccation; 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:

$$\frac{c_{u,k}}{p'_v} = k_1 R_o^{k_2} = k_1 \left(\frac{p'_{v,max}}{p'_v} \right)^{k_2} \quad (7)$$

where:

p'_v	is the effective overburden pressure;
$p'_{v,max}$	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 (7) may be taken as 0.23 ± 0.04 and 0.8 respectively, following *New developments in field and laboratory testing of soils* [22].

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 ($\phi'_{cv,k}$) may, in the absence of reliable test results, be estimated from:

$$\phi'_{cv,k} = (42^\circ - 12.5 \log_{10} l_p / p) \text{ for } 5\% \leq l_p \leq 100\% \quad (8)$$

where:

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

NOTE 1 Equation (8) is based on an expression proposed by Santamarina and Diaz-Rodriguez [23], which fits data presented by Terzaghi, Peck and Mesri [24].

NOTE 2 Values of $\phi'_{cv,k}$ based on this expression are given in [Table 2](#).

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

Plasticity index, I_p %	Characteristic constant volume angle of shearing resistance, $\varphi'_{cv,k}$ 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:

$$\varphi'_{pk} = \varphi'_{cv} + \varphi'_{dil} \quad (9)$$

where:

φ'_{cv} is the soil's constant-volume angle of shearing resistance; and
 φ'_{dil} is the contribution to φ'_{pk} 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}):

$$\varphi'_{res} \leq \varphi'_{cv} \leq \varphi'_{pk} \quad (10)$$

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 [2].

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%), $\varphi'_{cv,k}$ may, in the absence of reliable test data, be estimated from *Drained shear strength parameters for analysis of landslides* [25].

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:

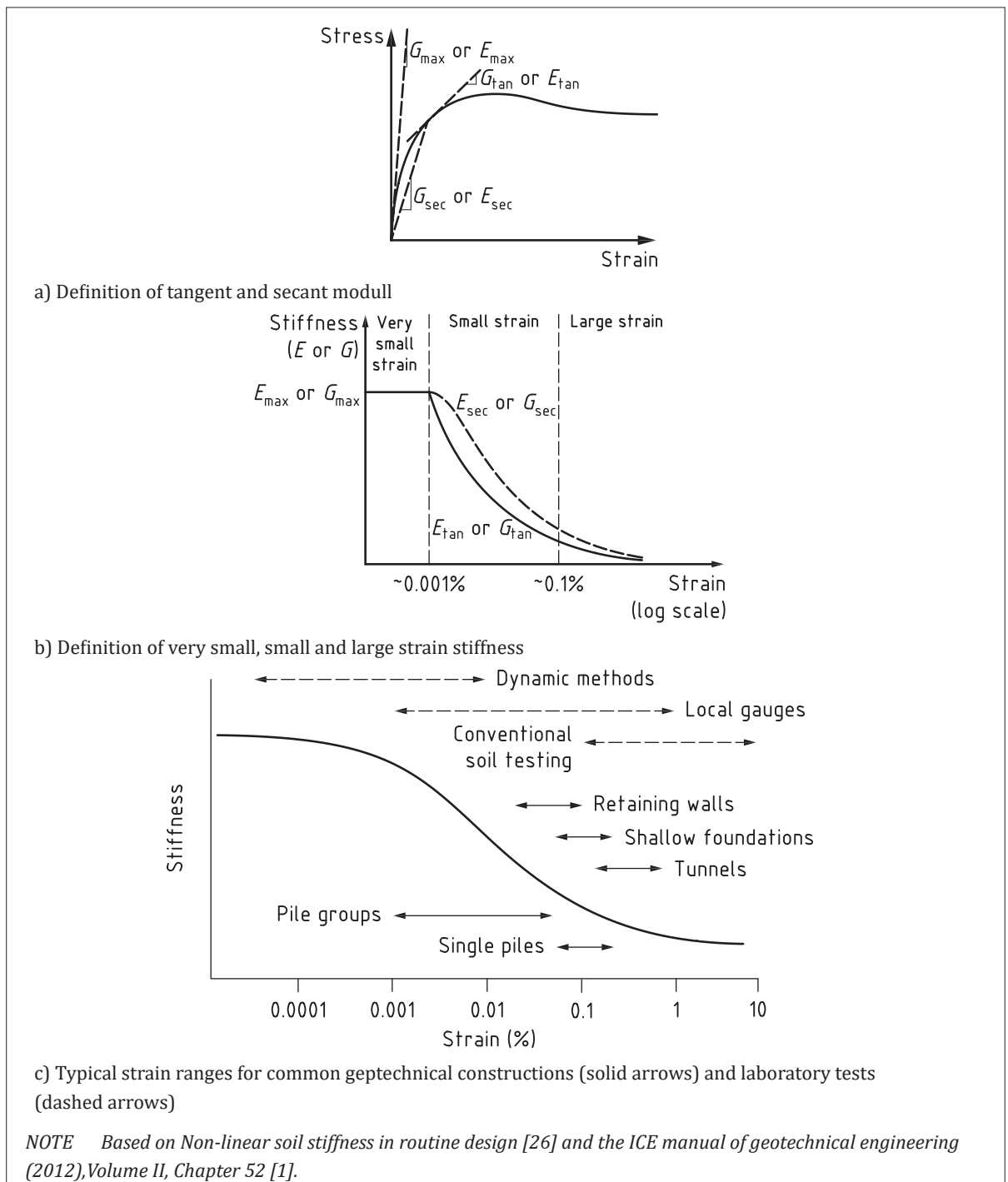
$$E = 2G(1 + \nu) \quad (11)$$

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 ($\sim 0.001\% \leq \epsilon$ 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_{hr} , G_{hv}).

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 In the absence of reliable test results, the secant shear modulus of a soil, G_{sec} , may be estimated from (see also *Stiffness of sands through a laboratory database* [27]):

$$\frac{G_{sec}}{G_{max}} = \left[1 + \left(\frac{\gamma - \gamma_e}{\gamma_{ref}} \right)^m \right]^{-1} \leq 1 \quad (12)$$

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 the reference value of engineering shear strain (at which $G_{\text{sec}} / G_{\max} = 0.5$); 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 (12) may be taken from [Table 3](#).

Table 3 — Values of parameters for use with equation (12)

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 [27]
Clays and silts	0.0022 I_p ^{B)}	0.736 ± 0.122 ^{C)}	0 (assumed)	Vardanega and Bolton [28]

^{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 stiffness in routine design* [26] and *Stiffness at small strain: research and practice* [29]):

$$\frac{G_{\max}}{p_{\text{ref}}} = \frac{k_1}{(1+e)^{k_2}} \left(\frac{p'}{p_{\text{ref}}} \right)^{k_3} \quad (13)$$

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 (13) may be taken from [Table 4](#).

Table 4 — Values of parameters for use with equation (13)

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 [30]
Sand	370–5 760 ^{B)}	3	0.49–0.86 ^{C)}	100 kPa	Oztoprak and Bolton [27]
Clays and silts	20 000 ± 5 000	2.4	0.5	1 kPa	Vardanega and Bolton [28]

Table 4 (continued)

Soil type	Parameter				Reference
	k_1	K_2	K_3	p_{ref}	
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 [19].

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

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 [2].

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 foundations should be properly investigated and classified.
- 4.3.3.2** Non-engineered fill, such as industrial, chemical, and domestic wastes, should not be placed beneath foundations.
- 4.3.3.3** Engineered fill comprising selected coarse granular soils, such as well-graded small rockfills, gravels, and sands, may be placed beneath foundations.
- 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 [19].

NOTE 2 Information about non-engineered fills can be found in the ICE manual of geotechnical engineering (2012), Volume 1, Chapter 34 [2].

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 [31].

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 is 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 a foundation 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 [32].

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 a foundation, allowance should be made for seepage around the $\overline{A_1}$ foundation $\overline{A_1}$. 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.

4.3.6 Concrete

4.3.6.1 Concrete incorporated into foundations should conform to BS EN 1992-1-1, BS EN 206, and BS 8500-2.

4.3.6.2 Concrete incorporated into foundations should be specified in accordance with BS EN 206 and BS 8500-1.

4.3.6.3 Steel reinforcement for concrete foundations should conform to BS EN 10080 and BS 4449.

4.3.7 Steel

4.3.7.1 Steel incorporated into foundations should conform to BS EN 1993-1-1, BS EN 1993-5, and BS 8081, as appropriate.

4.3.7.2 The values of steel parameters should be determined in accordance with BS EN 1993-1-1 and BS EN 1993-5, and their UK National Annexes.

- 4.3.7.3** Hot rolled steel products should conform to [BS EN 10025](#).
- 4.3.7.4** Hot rolled steel products manufactured to a different standard than [BS EN 10025](#) may be used if it can be demonstrated by appropriate additional testing that the products meet the requirements of [BS EN 10025](#) that are relevant to the foundation.
- 4.3.7.5** Cold formed hollow steel sections should conform to [BS EN 10219](#).
- 4.3.7.6** Cold formed hollow steel sections manufactured to a different standard than [BS EN 10219](#) may be used if it can be demonstrated by appropriate additional testing that the sections meet the requirements of [BS EN 10219](#) that are relevant to the foundation

4.3.8 Timber

- 4.3.8.1** Timber incorporated into foundations should conform to BS EN 1995-1-1.
- 4.3.8.2** The values of timber parameters should be determined in accordance with BS EN 1995-1-1.

4.3.9 Masonry

- 4.3.9.1** Masonry incorporated into foundations should conform to BS EN 1996-1-1.
- 4.3.9.2** The values of masonry parameters should be determined in accordance with BS EN 1996-1-1.
- 4.3.9.3** The following masonry units should conform to the relevant part of [BS EN 771](#):
- clay masonry units (Part 1);
 - calcium silicate masonry units (Part 2);
 - aggregate concrete masonry units (Part 3);
 - autoclaved aerated concrete masonry units (Part 4);
 - manufactured stone masonry units (Part 5); and
 - natural stone masonry units (Part 6).
- 4.3.9.4** The dimensions of clay and calcium silicate brick of special shapes and sizes should conform to [BS 4729](#).
- 4.3.9.5** Mortars used in masonry foundations should conform to PD 6697.
- 4.3.9.6** Damp proof courses used in masonry foundations should conform to [BS 8215](#).
- 4.3.9.7** Wall ties should conform to PD 6697.

4.3.10 Pipes

Pipes used in drainage systems for foundations should conform to one of the following standards, as appropriate:

- vitrified clay pipes – [BS 65](#) and [BS EN 295](#);
- concrete pipes – [BS 5911](#) and BS EN 1916;
- glass reinforced plastics (GRP) pipes – BS 5480;
- cast iron – [BS 437](#);
- ductile iron – BS EN 598;
- unplasticised polyvinyl-chloride (PVC-U) – [BS 4660](#) or [BS 5481](#) or BS EN 1401-1;
- polypropylene (PP) – BS EN 1852-1;

- polyethylene (PE) – BS EN 12666-1;
- thermoplastics structure wall pipes – [BS 4962](#);
- geotextile wrapped land drains – [BS 4962](#).

4.4 Durability

4.4.1 General

The durability of foundations should conform to BS EN 1990.

4.4.2 Concrete

4.4.2.1 The durability of concrete should conform to BS EN 1992-1-1.

4.4.2.2 Exposure classes for concrete should be determined in accordance with BS EN 206 and [BS 8500-1](#).

4.4.2.3 For the purpose of specifying concrete to be used in foundations, ground conditions should be classified in accordance with [BS 8500-1:2015](#), Table A.2.

NOTE 1 [BS 8500-1:2015](#) and [BS 8500-2:2015](#) are complementary British Standards to BS EN 206:2013.

NOTE 2 Guidance on concrete in aggressive ground can be found in BRE Special Digest 1 [\[33\]](#).

4.4.3 Steel

4.4.3.1 The durability of steel should conform to BS EN 1993-1-1.

4.4.3.2 The durability of steel reinforcement in reinforced concrete should conform to BS EN 1992-1-1.

NOTE Guidance on corrosion at bi-metallic contacts and its remediation can be found in PD 6484.

4.4.4 Timber

4.4.4.1 General

NOTE 1 Information on the biological agents that can attack wood can be found in BS EN 335:2013, Annex C.

NOTE 2 Guidance on shipworm (various species of the genera *Teredo* and *Banksia*), *Martesia*, and gribble (various species of the genus *Limnoria*) can be found in BRE Technical Note 59 [\[34\]](#).

4.4.4.1.1 The preservative treatment of timber should conform to [BS 8417](#).

4.4.4.1.2 Components should be machined so that they contain a high proportion of permeable sapwood.

NOTE Wood species can be selected for permeability and sapwood content from the information given in BS EN 350-2.

4.4.4.1.3 The durability of timber should conform to BS EN 1995-1-1, which requires timber and wood-based materials to have either:

- adequate natural durability conforming to BS EN 350-2 for the particular hazard class defined in BS EN 335-1:1992, BS EN 335-2:1992, and BS EN 335-3:1992, or
- be given a preservative treatment selected conforming to BS EN 351-1 and BS EN 460.

NOTE BS EN 335-1:1992, BS EN 335-2:1992, and BS EN 335-3:1992 have been superseded by BS EN 335:2013.

4.4.4.1.4 All machining of timber, including notching, should be undertaken before applying preservative treatment.

4.4.4.2 Service classes

Service classes for timber should be determined in accordance with BS EN 1995-1-1.

4.4.4.3 Use classes

Use classes for timber should be determined in accordance with BS EN 335.

NOTE 1 Use classes relevant to timber in earth retaining structures are summarized in Table 5.

NOTE 2 BS EN 1995-1-1:2004 requires timber structures to be assigned to one of three “service classes”.

BS EN 335:2013 defines five “use classes” for wood and wood-based products. BS EN 335:2013, Annex A provides a possible mapping of service classes to use classes.

Table 5 — Use classes relevant to timber in foundations

Use class	Situation	Attack is possible by:
UC 4	Wood is in direct contact with the ground or fresh water	Fungi and wood-destroying fungi Wood-boring insects Termites (in countries where these present a hazard) Bacterial decay
UC 5	Wood is permanently or regularly submerged in salt water (i.e. sea water and brackish water)	Invertebrate marine organisms Wood-destroying fungi Growth of surface moulds and staining fungi Wood-boring insects (above water)

4.4.5 Masonry

The durability of masonry foundations should conform to BS EN 1996-1-1, BS EN 1996-2, and PD 6697.

4.5 Geotechnical analysis

4.5.1 The actions assumed in the geotechnical analysis of foundations should conform to [BS EN 1991](#).

4.5.2 The actions assumed in the geotechnical analysis of foundations subject to traffic loading should additionally conform to the UK National Annex to BS EN 1991-2 and to PD 6694-1.

4.5.3 To conform to BS EN 1990:2002+A1:2005, **6.4.3.3(4)**, combinations of actions for accidental design situations should include either the accidental action itself or actions that occur after the accidental event.

4.5.4 The effects of dynamic and cyclic loads on the performance of a foundation should be considered.

4.5.5 For the verification of limit states GEO, EQU, and STR, the value of load classification factor defined in BS EN 1991-2:2003 should be taken as $\alpha = 1.1$. This factor should be applied to the equivalent vertical loading for earthworks and the earth pressure effects due to rail traffic actions, according to the requirements of BS EN 1991-2:2003, **6.3.2(3)P** and **6.3.6.4**.

4.6 Ultimate limit states

4.6.1 General

The ultimate limit state design of a foundation should conform to BS EN 1997-1:2004+A1:2013, **2.4.7**.

4.6.2 Design values of geotechnical parameters

COMMENTARY ON 4.6.2

The UK National Annex to BS EN 1997-1:2004+A1:2013 states that “it might be more appropriate to determine the design value of ϕ'_{cv} directly, rather than apply the partial factor γ_ϕ ($= 1.25$ for limit state GEO, Set M2) to its characteristic value”.