

Australian Standard[®]

Piling—Design and installation



This Australian Standard® was prepared by Committee CE-018, Piling. It was approved on behalf of the Council of Standards Australia on 19 June 2009.
This Standard was published on 4 November 2009.

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- Australian Building Codes Board
 - Australian Geomechanics Society
 - AUSTROADS
 - Concrete Institute of Australia
 - Engineers Australia
 - Monash University
 - Piling and Foundation Specialists Federation
 - University of Sydney
-

This Standard was issued in draft form for comment as DR 08180.

Standards Australia wishes to acknowledge the participation of the expert individuals that contributed to the development of this Standard through their representation on the Committee and through the public comment period.

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Australian Standard[®]

Piling—Design and installation

Originated as AS 2159—1978.
Third edition 2009.
Reissued incorporating Amendment No. 1 (October 2010).

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Published by SAI Global Limited under licence from Standards Australia Limited, GPO Box 476, Sydney, NSW 2001, Australia

ISBN 0 7337 9286 3

PREFACE

This Standard was prepared by the Standards Australia Committee CE-018, Piling, to supersede AS 2159—1995.

This Standard incorporates Amendment No. 1 (October 2010). The changes required by the Amendment are indicated in the text by a marginal bar and amendment number against the clause, note, table, figure or part thereof affected.

The objective of this Standard is to provide requirements for design and installation of piles for supporting structures. The object of this revision is to align with updated AS 1170 Standards and reflect changes in practice since the previous edition.

Major changes to the previous edition are as follows:

- (a) Revision of the overall Standard.
- (b) Revision of the setting of strength reduction factors, that is, the selection of the ‘safety’ level appropriate to the installation being designed.
- (c) Revision of the negative skin friction requirements.
- (d) Revision of durability requirements to assist designers to achieve predicted life.
- (e) Include requirements for newer pile types and installation methods including steel screw piles, jacking, screwing and screwed cast in place.
- (f) Requirement for some testing to be ‘normative’.
- (g) Inclusion of new types of test including rapid pile testing.

The terms ‘normative’ and ‘informative’ have been used in this Standard to define the application of the appendix to which they apply. A ‘normative’ appendix is an integral part of a Standard, whereas an ‘informative’ appendix is only for information and guidance.

Statements expressed in mandatory terms in notes to tables are deemed to be requirements of this Standard.

Notes to the text contain information and guidance and are not considered to be an integral part of the Standard.

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FOREWORD

Decisions in pile design are based on design formulae, empirical and practical experience, and the accumulated records of a large number of applications of proprietary systems (both successful and otherwise). As such, there is a great need for flexibility, experience, engineering judgement and commonsense in designing and constructing a piled footing system. In a real sense, these requirements are in conflict with the need to make unqualified mandatory statements and, as a result, many of the stipulations of this Standard are short and simple when, in other cases, extensive arrays of multiple choices are provided. Where applicable, explanatory notes are added to some clauses in this Standard and additional commentary is provided.

STANDARDS AUSTRALIA

Australian Standard

Piling—Design and installation

SECTION 1 SCOPE AND GENERAL

1.1 SCOPE

This Standard sets out minimum requirements for the design, construction and testing of piled footings for civil engineering and building structures on land or immediate inshore locations. It does not extend to offshore (deepwater) construction.

NOTES:

- 1 AS 5100 series should be considered for the design of footings for road bridges.
- 2 Where the strength or serviceability of an existing structure is to be evaluated, the general principles of this Standard should be applied. The actual properties of the materials in the structure should be used.
- 3 The durability requirements are appropriate for structures with design life within $\pm 20\%$ of the target design life.

1.2 NORMATIVE REFERENCES

The normative documents referenced in this Standard are the following:

NOTE: Documents referenced for informative purposes are listed in the Bibliography.

AS

1012	Methods of testing concrete (all Parts)
1163	Structural steel hollow sections
1170	Structural design actions
1170.4	Part 4: Earthquake actions in Australia
1289	Methods of testing soils for engineering purposes
1289.6.3.1	Part 6.3.1: Soil strength and consolidation tests—Determination of the penetration resistance of a soil—Standard penetration test (SPT)
1289.6.5.1	Part 6.5.1: Soil strength and consolidation tests—Determination of the static cone penetration resistance of a soil—Field test using a mechanical and electrical cone or friction-cone penetrometer
1379	Specification and supply of concrete
1450	Steel tubes for mechanical purposes
1554	Structural steel welding
1554.1	Part 1: Welding of steel structures
1579	Arc-welded steel pipes and fittings for water and waste-water
1604	Specification for preservative treatment
1604.1	Part 1: Sawn and round timber
1720	Timber structures
1720.1	Part 1: Design methods
1726	Geotechnical site investigations

AS

- 2758 Aggregates and rock for engineering purposes
- 2758.1 Part 1: Concrete aggregates
- 2832 Cathodic protection of metals
- 2832.2 Part 2: Compact buried structures
- 2832.3 Part 3: Fixed immersed structures
- 3600 Concrete structures
- 3818 Timber—Heavy structural products—Visually graded
- 3818.3 Part 3: Piles
- 3972 Portland and blended cements
- 4100 Steel structures
- 5100 Bridge design
- 5100.5 Part 5: Concrete
- 5100.6 Part 6: Steel and composite construction

AS/NZS

- 1170 Structural design actions
- 1170.0 Part 0: General principles
- 1594 Hot-rolled steel flat products
- 3678 Structural steel—Hot-rolled plates, floorplates and slabs
- 3679 Structural steel
- 3679.1 Part 1: Hot-rolled bars and sections
- 3679.2 Part 2: Welded I sections
- 4671 Steel reinforcing materials

ASTM

- C 566-97 Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying

1.3 DEFINITIONS

For the purpose of this Standard, the definitions below apply.

1.3.1 Bored cast in place pile

A pile, with or without a liner, formed by excavating or boring a hole in the ground and subsequently filling it with plain or reinforced concrete.

1.3.2 Cased pile

A pile formed in the ground by installing a liner and partially or wholly filling it with plain or reinforced concrete after excavation.

1.3.3 Cone penetration test (CPT)

A test in accordance with AS 1289.6.5.1, to determine the penetration resistance of a soil.

1.3.4 Continuous flight auger pile (CFA)

A pile formed in the ground by drilling with a hollow flight auger that is subsequently and progressively withdrawn, with the cavity below the auger tip being gradually filled with concrete or cement grout injected under pressure.

1.3.5 Design action

Combination of the nominal loads and other actions multiplied by the appropriate load factors.

1.3.6 Design action effect (E_d)

Action effect computed from the design values of the actions or design loads.

1.3.7 Design geotechnical strength ($R_{d,g}$)

The product of the design ultimate geotechnical strength ($R_{d,ug}$) and the geotechnical strength reduction factor (ϕ_g).

1.3.8 Design life

Period of time during which a structure or a structural element, when designed, is assumed to perform for its intended purpose with expected maintenance but without major structural repair being necessary.

1.3.9 Design serviceability load (E_{ds})

The load on a pile corresponding to the serviceability limit state.

1.3.10 Design structural strength ($R_{d,s}$)

The product of the design ultimate structural strength ($R_{d,us}$) and the structural strength reduction factor (ϕ_s).

1.3.11 Design ultimate geotechnical strength ($R_{d,ug}$)

An estimate of the ultimate geotechnical strength assessed using calculations in accordance with Section 4 of this Standard.

1.3.12 Design ultimate structural strength ($R_{d,us}$)

The limit state at which static equilibrium is lost, or at which structural elements fail.

NOTE: The design ultimate structural strength may be assessed using calculations in accordance with Section 5 of this Standard.

1.3.13 Driven cast in place pile

A pile formed by driving a liner, which is either permanent or temporary, and filling with plain or reinforced concrete.

1.3.14 Driven preformed pile

A prefabricated pile installed in the ground by driving.

1.3.15 Durability

Ability of a structure or a structural element to maintain adequate performance for a given time under expected actions and environmental influences.

1.3.16 End-bearing pile

A pile where the major component of the resistance of the pile is contributed by the force developed at the base of the pile.

1.3.17 Footing

A part of a structure in direct contact with and transmitting load to the supporting foundation.

1.3.18 Foundation

The soil, subsoil or rock, whether built-up or natural, upon which a structure is supported.

NOTE: The term 'foundation' is commonly used to mean both the footing and the ground supporting the footing.

1.3.19 Friction pile

A pile where the major component of the resistance of the pile is contributed by the force developed along the shaft of the pile.

1.3.20 Ground anchor

A tendon anchored into the ground by bond and used to provide a reaction for test loading piles.

1.3.21 Large displacement piles

Preformed or cast in place piles, generally with a solid cross-section dimension of at least 300 mm, installed by driving, screwing, pushing, vibrating or similar methods, which cause a displacement such that significant stresses are induced in the surrounding soils, which may increase the load capacity of the pile and cause displacement of the surrounding soils.

1.3.22 Limit state

Condition for which a system is designed, and beyond which it ceases to fulfil its intended function and becomes unfit for use.

NOTE: There are recognized limit states, e.g., for fire, serviceability, stability and strength.

1.3.23 Pile

A structural member that is driven, screwed, jacked, vibrated, drilled or otherwise installed in the ground so as to transmit loads to the underlying soil or rock and provide a foundation for structure.

1.3.24 Pile group

Number of piles installed in close proximity and usually having a common pile cap.

1.3.25 Pile head

Top of a pile.

1.3.26 Pile heave

Displacement (usually vertical) of a pile caused by the driving, or by external ground movements, of piles in close proximity.

1.3.27 Raking pile

A pile installed at an angle to the vertical.

1.3.28 Serviceability limit state (SLS), serviceability

A limit state beyond which specified service criteria are no longer met, such as unacceptably large displacements, vibrations, cracking, spalling and other local damage.

1.3.29 Set

Permanent penetration of a driven pile or liner per blow of the hammer.

1.3.30 Small displacement piles

Preformed or cast in place piles, generally with a hollow cross-section or a solid cross-section dimension less than 300 mm, installed by driving, screwing, pushing, vibrating or similar methods, which cause a small displacement such that significant stresses or displacements are not induced in the surrounding soils.

1.3.31 Standard penetration test (SPT)

A test in accordance with AS 1289.6.3.1, to determine the penetration resistance of a soil.

1.3.32 Steel screw piles

Preformed small displacement piles installed by rotating a steel pipe, which has one or more spiral flights (helices) welded to it.

1.3.33 Temporary compression

The temporary pile-head deflection during a hammer blow, comprising elastic deflection of the pile cushion, the pile and the soil.

1.3.34 Test pile

Pile subjected to a loading test with the primary purpose of establishing the load deformation characteristics, and/or the ultimate structural strength of the pile, and/or the ultimate geotechnical strength of the pile/soil system.

1.3.35 Test ultimate geotechnical strength ($R_{t,ug}$)

An estimate of the ultimate geotechnical strength assessed from a load test carried out in accordance with Section 8 of this Standard.

1.3.36 Toe

The base of the pile.

1.3.37 Ultimate geotechnical strength (R_{ug})

The resistance developed by an axially or laterally loaded pile or pile group at which static equilibrium is lost or at which the supporting ground fails.

1.4 NOTATION

The symbols used in this Standard are listed below. Unless a contrary indication appears elsewhere, the symbols used in this Standard shall be as defined below. The notations in Clause 3.3, relating to load and combinations in AS 1170.4, have not been incorporated in this table.

TABLE 1.1
NOTATION

Symbol	Term	Text reference
A_b	Plan area of pile base	Clauses 4.4.1, 4.4.2
A'_b	Net area of pile base resisting uplift, i.e., the difference between cross-sectional areas of the pile base and the pile shaft	Clause 4.4.2
A_g	Area of the pile cross-section	Clause 5.3.3(b)
ARR	Average risk rating for overall design	Clause 4.3.2, Table 4.3.2 (C)
A_s	Surface area of pile in intimate contact with soil	Clauses 4.4.1, 4.4.2
A_{sc}	Cross-sectional area of compression reinforcement	Clause 5.3.3(b)
c	Pile wave speed	Paragraph C2.2, Appendix C
d	Pile diameter	Clause 5.6.3.2, Table 8.4.3.1
d_b	Diameter of longitudinal steel	Clause 5.3.7
d_t	Pile base (toe) diameter	Tables 8.4.3.1, 8.5.2
D_d	Dowel diameter	Clause 5.6.3.2
D	Overall minimum width of pile in plane of bending	Clause 5.2.2(b)
E	Average Young's modulus of pile	Tables 8.4.3.1, 8.5.2

(continued)

TABLE 1.1 (continued)

Symbol	Term	Text reference
E_d	Design action effect	Clauses 1.3.6, 3.2.2(b), 5.4.2.3, 3.2.2(d), 4.3.1, 5.2.1, 8.3.3.4, Paragraph B8, Appendix B, Tables 8.3.3.2, 8.3.3.4 and E1, Appendix E
E_{ds}	Design serviceability load	Clauses 1.3.9, 4.6.3(a), Paragraph B8, Appendix B, Tables 8.3.3.2, 8.3.3.3, 8.4.3.1, 8.5.2 and E1, Appendix E
F_{eh}	Bending moments, shear forces and axial actions induced by heave due to unloading of ground due to excavation	Clauses 3.3.1.2(d), 3.3.2(b)
F_{em}	Bending moments, shear forces and axial actions induced by lateral ground movements	Clauses 3.3.1.2(c), 3.3.2(b)
F_{es}	Compressive and tensile actions in the pile induced by vertical ground movements	Clauses 3.3.1.2(b), 3.3.2(b)
F_{nf}	Actions due to negative friction	Clauses 3.3.1.2(a), 3.3.2(b), 4.6.3, Tables 8.3.3.3, 8.4.3.1 and E1, Appendix E
f_b	Ultimate base pressure for compression pile	Clause 4.4.1
f_{bt}	Ultimate base pressure for uplift pile	Clause 4.4.2
f'_c	Characteristic concrete strength	Table 6.4.3
f'_{cm}	Characteristic strength of concrete at relevant age	Clause 7.3.3.1(a), Table 7.3.3.1
$f_{m,s}$	Average skin friction for condition of full mobilization—Compression pile	Clause 4.4.1
$f_{m,st}$	Average skin friction for condition of full mobilization—Tension pile	Clause 4.4.2
f_{sy}	Yield stress for reinforcement in concrete piles	Clauses 7.3.3.1(b), 7.3.2.
g	Acceleration due to gravity (9.8 m/s^2)	Paragraph C5.4, Appendix C
h	Depth to cut-off	Clause 7.2.1(b)
IRR	Individual risk rating for risk factor	Clause 4.3.2, Tables 4.3.2(A), 4.3.2(B)
k	Concrete placement factor	Clause 5.2.1, 5.3.2, 5.3.6
K	Testing benefit factor	Clause 4.3.1
l_1	Minimum edge distance to head of pile	Clause 5.6.3.2
L_{nf}	Length of the test pile in contact with ground expected to undergo long-term settlement	Tables 8.4.3.1, 8.5.2
L	Pile length	Tables 8.4.3.1, 8.5.2, Paragraph C2.3, Appendix C
M_d	Design bending moment	Clause 5.2.2
N_d	Design axial load	Clause 5.2.2(b)
p	Percentage of total piles tested that meet the specified acceptance criteria	Clause 4.3.1

(continued)

TABLE 1.1 (continued)

Symbol	Term	Text reference
P_g	Maximum test load for assessment of geotechnical ultimate limit state $R_{t,ug}$	Clauses 8.3.3.1, 8.3.3.2, 8.3.3.4, 8.5.2, Paragraph A3.1, Appendix A, Paragraph B1, Appendix B, Tables 8.4.3.1, 8.5.2, A1, A2, Appendix A
p_o	Total overburden pressure at base level	Clause 4.4.1
P_{max}	Pile jacking installation force	Clause 7.3.4.1
P_s	Maximum test load for assessment of pile performance at serviceability limit state = E_{ds}	Clauses 8.3.3.1, 8.3.3.2, Paragraph B1, Appendix B, Tables 8.3.3.2, 8.3.3.3, 8.4.3.1, 8.5.2, A1, A2, A3, Appendix A, B1, Appendix B
P_u	Maximum test load for assessment of design geotechnical ultimate limit state	Clauses 8.3.3.1, 8.3.3.2, Paragraph A3.1, Appendix A and Paragraph B1, Appendix B Tables 8.3.3.2, 8.3.3.3, 8.4.2, 8.4.3.1, A1, Appendix A
$R_{d,g}$	Design geotechnical strength of pile	Clauses 1.3.7, 3.2.2(c), 3.2.2(d), 4.3.1, Table E1, Appendix E
$R_{d,s}$	Design structural strength of pile	Clauses 1.3.10, 3.2.2(c), 3.2.2(d), 5.2.1, 5.4.2.3, Table E1, Appendix E
$R_{t,ug}$	Ultimate geotechnical strength of a pile as assessed from a load test carried out in accordance with Section 8 of this Code	Clauses 1.3.35, 8.4.2.2, 8.4.3.5, Tables 8.3.3.2, 8.3.3.3, E1, Appendix E
R_{ug}	Ultimate geotechnical strength of pile. This is estimated either by calculation ($R_{d,ug}$) or by test ($R_{t,ug}$)	Clauses 1.3.37, 7.3.4.1, Tables 8.3.3.2, 8.4.2, E1, Appendix E
R_{us}	Ultimate structural strength of pile	Clauses 5.2.1, 5.3.1, 5.3.2, Table E1, Appendix E
$R_{d,ug}$	Design ultimate geotechnical strength of pile (ultimate load capacity)	Clauses 1.3.7, 1.3.11, 4.3.1, 4.3.3, 4.4.2, 4.4.4, 8.2.4, Table E1, Appendix E
$R_{d,g,c}$	Design ultimate geotechnical strength of combined pile and raft foundation	Clause 4.4.4, Table E1, Appendix E
$R_{d,us}$	Design ultimate structural strength of pile	Clause 1.3.10, 1.3.12,
$R_{d,ug,s}$	Design ultimate geotechnical strength of shallow or raft footing, for the net area in contact with the supporting ground	Clause 4.4.4, Table E1, Appendix E
$R_{d,ug,sz}$	Design ultimate geotechnical strength of pile in stable zone, i.e., the soil strata not subject to externally imposed ground settlements	Clause 4.6.3, Table E1, Appendix E
S_u	Ultimate value of various actions appropriate for particular combinations	Clause 3.3.2(b)
W	Weight of pile	Clauses 4.4.1, 4.4.2
w_i	Weighting factor for individual risk ratings	Clause 4.3.2, Tables 4.3.2(A)
γ_p	Coefficient of jacked pressure	Clause 7.3.4.1

(continued)

TABLE 1.1 (continued)

Symbol	Term	Text reference
δ	Pile movements	Clause 3.2.3
ϕ_g	Geotechnical strength reduction factor for single piles or pile groups	Clauses 4.3.1, 4.4.4, 4.6.3, 8.3.3.4, Paragraph B8, Appendix B, Table 8.3.3.2
ϕ_{gb}	Basic geotechnical strength reduction factor given in Clause 4.3.2	Clauses 4.3.1, 4.3.2
ϕ_{gs}	Geotechnical strength reduction factor for the shallow or raft footing	Clause 4.4.4
ϕ_s	Structural strength reduction factor for single piles or pile groups	Clauses 1.3.10, 5.2.1, 5.3.1, 5.3.4, 5.3.5, 5.4.2.3
ϕ_{tf}	Intrinsic test factor	Clause 4.3.1

1.5 CLASSIFICATION OF PILES

1.5.1 General

The classification of pile types used in this Standard is illustrated in Figure 1.5. Pile types are broadly classified into ‘displacement’ and ‘non-displacement’ piles and further subdivided on the basis of the method of pile installation and formation.

1.5.2 Displacement piles

Displacement piles are defined as those that displace the ground through which they are being installed. To operate as a displacement pile, the displaced volume shall approximate the pile volume.

Displacement piles may be installed by hammering, pushing, screwing, vibrating or other means to force them into the ground.

Displacement piles may be one of the following:

- (a) *Preformed* Solid and hollow sections that are installed in the ground and left in position. Such piles may be extended by splicing on additional lengths of piling. Preformed piles may be fabricated from—
 - (i) concrete, reinforced or prestressed;
 - (ii) steel—H Section, tube and other sections;
 - (iii) timber; or
 - (iv) a combination of concrete, steel or timber sections.
- (b) *Driven cast in place* Pile formed in situ by driving a tubular liner to form a void, which is then wholly or partially filled with concrete or grout. The liner may be either—
 - (i) *permanent*—made of concrete or steel with open or closed ends of constant or tapered section; or
 - (ii) *temporary*—steel tube extracted during concreting or grouting, with or without an expanded base.
- (c) *Screwed cast in place* Piles formed in situ by screwing a threaded tube into the ground with concrete placement as the screw head is withdrawn.

1.5.3 Non-displacement piles

1.5.3.1 General

Piles formed in situ by removing soil, using either rotary drilling, percussion, reverse circulation, grabbing, chiselling and mechanical or hand excavation methods, to form a void, which is then filled with concrete or grout. During removal of the soil, the sides of the excavated void may or may not be supported.

1.5.3.2 Supported

The support may be either—

- (a) *permanent*—using steel, concrete or other liners; or
- (b) *temporary*—using—
 - (i) steel, concrete or other liners or timber shoring;
 - (ii) drilling fluids; or
 - (iii) continuous flight augers.

1.5.3.3 Unsupported

Piles in which the ground is left exposed during excavation.

1.5.4 Partial displacement, post-grouted and preloaded non-displacement piles

Various techniques, such as partial displacement augers, post-grouting of the shaft or base and preloading the base of non-displacement piles, are used to improve the performance of non-displacement piles.

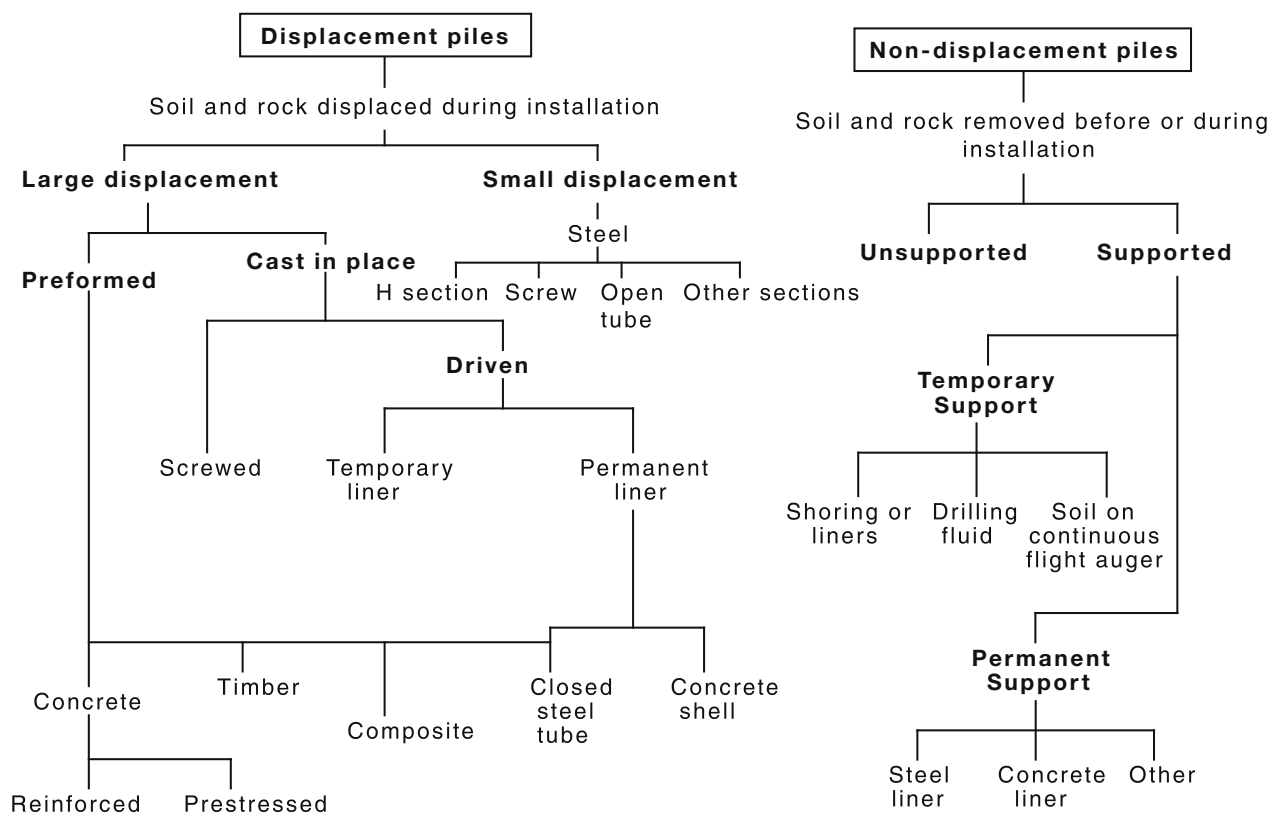


FIGURE 1.5 CLASSIFICATION OF PILE TYPES

SECTION 2 SITE INVESTIGATION

2.1 GENERAL

For any site on which it is proposed to install piles, site investigation shall be carried out to provide sufficient information to fulfil the requirements of Clause 2.2. When planning the site investigation, existing relevant information shall be taken into account.

NOTE: The intention of this Section is to ensure that adequate information is available for design and construction.

2.2 INFORMATION REQUIRED

Appropriate site investigations shall provide information on geotechnical conditions according to AS 1726, as follows:

- (a) The geotechnical design of piles.
- (b) Assessment of geotechnical conditions for pile construction or installation.
- (c) Some additional site-specific aspects, including—
 - (i) potential for ground heave—damage to adjacent structures or neighbouring piles;
 - (ii) vibration effects—potential for damage to adjacent structures;
 - (iii) expansive soil problems;
 - (iv) potential difficulties with pile cap construction;
 - (v) groundwater conditions;
 - (vi) negative friction effects;
 - (vii) near-surface conditions or lateral load design, if relevant;
 - (viii) possible obstructions to installation, e.g., boulders or old footings or piles;
 - (ix) potential for slope instability;
 - (x) effects of excavation or scour;
 - (xi) effects of contaminated sites;
 - (xii) an assessment of the site surface for the provision of a safe work platform for piling equipment;
 - (xiii) potential for acid sulfate soils; and
 - (xiv) potential for weak or compressible layers, or caverns below the pile base, including soils below lava flows.
- (d) Assessment of the potential effects of site conditions on pile durability.

NOTE: The site investigation should obtain information on all materials that might influence the strength and serviceability performance of the structure. Due account should be taken of the range of foundation options that might apply. This should include testing of the soil and groundwater for aggressive agents, including sulphate, chloride and pH, to ensure appropriate exposure classification in regard to durability.

SECTION 3 DESIGN REQUIREMENTS AND PROCEDURES

3.1 OBJECTIVE OF PILE DESIGN

The objective of pile design is to provide a footing that will safely support the superstructure over its design life.

3.2 GENERAL DESIGN REQUIREMENTS

3.2.1 General

The footing shall be durable, and of adequate strength, and the footing performance shall be compatible with the superstructure so that it remains serviceable and can perform its intended function.

The design shall take into account, as appropriate, the following:

- (a) *Ultimate strength* The limit state at which static equilibrium is lost or at which there is a failure of the supporting ground or structural elements. To be of adequate ultimate strength, the probability of structural or geotechnical failure of the piles shall be acceptably low throughout the intended design life of the structure. The ultimate strength of piles shall be checked for both structural and geotechnical adequacy.
- (b) *Serviceability* The limit state at which deformation of the piles will cause damage or loss of serviceability in the structure.
- (c) *Durability* The piles shall be able to withstand the expected wear and deterioration throughout the intended design life of the structure.
- (d) *Other* Other relevant design requirements.

The relevant action effects for ultimate and serviceability limit states and deflection limits to be used in the design of the piles shall be determined from the analysis of the supported structure.

NOTE: Where foundations are being designed separately to the supported structure, the values of ultimate and serviceability loads, and deflection and differential deflection limits, should be indicated on the drawings, or otherwise provided in order to facilitate the design.

3.2.2 Design for ultimate strength

Single piles, pile groups and individual piles within a pile group shall be designed for both structural and geotechnical strength as follows:

- (a) The design load for strength shall be determined from Clause 3.3.2 using the appropriate loads and other actions listed in Clause 3.3.1.
- (b) In the design of a single pile or pile group, the various factored design loads and other actions (including the effects of eccentricities due to construction tolerances) shall be applied to that single pile or pile group, and the design action effect (E_d) determined for each pile or pile group for each load case.
- (c) The design geotechnical strength ($R_{d,g}$) and the design structural strength ($R_{d,s}$) shall be determined in accordance with the requirements of Sections 4 and 5, as appropriate.
- (d) The pile or pile group shall be proportioned so that the design geotechnical strength and the design structural strength are not less than the design action effect, that is—

$$R_{d,g} \geq E_d; \text{ and} \quad \dots 3.2.2(1)$$

$$R_{d,s} \geq E_d \quad \dots 3.2.2(2)$$

In addition to the design of each pile in a group, the geotechnical strength of the group as a single unit shall be analysed for failure under the design action effect for the pile group.

The geotechnical design strength of the group shall comply with the provisions of Clauses 4.4.3 and 4.4.5. It is permissible to allow for the sharing of a load between piles and pile caps, or for the sharing of a load among piles, provided an analysis demonstrates that the complete pile system operates within the general principles of this Standard even though individual piles may not.

3.2.3 Design for serviceability

Single piles and pile groups shall be designed for serviceability by controlling or limiting pile movements (δ) including differential and total settlements, horizontal displacement and rotation.

Under the serviceability loadings resulting from the load combinations for serviceability design determined from Clause 3.3.3, pile movements shall be limited to ensure that the foundations and the structure remain serviceable throughout their design lives in accordance with the requirements of Section 4.

3.2.4 Design for durability

Piles shall be designed for durability in accordance with Section 6.

3.2.5 Design for other relevant requirements

Any special design criteria, such as stability, scour, fatigue, cyclic loading or seismic actions, shall be considered. Where relevant, these shall be taken into account in the design of the piles in accordance with the principles of this Standard and other appropriate engineering principles.

3.3 ACTIONS AND COMBINATIONS FOR STRENGTH AND SERVICEABILITY DESIGN

3.3.1 Actions and loads

3.3.1.1 General

The design of a pile for ultimate strength and serviceability limit states shall take account of appropriate action effects arising from the following:

- (a) All actions specified in AS/NZS 1170.0 and other relevant actions.
- (b) Permanent actions of pile and pile cap.
- (c) Ground movement, including negative friction, expansive soils, and vertical and lateral earth movements that may arise from various sources.
- (d) Handling.
- (e) Installation.
- (f) Any other additional loads and actions that may be applied, e.g., impact, dynamic loading, water pressures and scour.

3.3.1.2 Ground movement

Allowance shall be made for actions induced by ground movements, as follows:

- (a) Where a pile is situated in ground undergoing settlement, allowance shall be made for actions (F_{nf}) due to negative friction acting on the pile.
- (b) Where a pile is situated in swelling soils, such as reactive clays or those subjected to frost action, allowance shall be made for the compressive and tensile actions (F_{es}) that may be developed in the pile.

- (c) Where a pile is subjected to lateral ground movements, allowance shall be made for bending moments, shear forces and axial actions (F_{em}) induced by such movements. These bending moments, shear forces and axial actions shall be determined using an appropriate soil-structure analysis.
- (d) Where a pile is subjected to heave due to unloading of the ground via excavation, allowance shall be made for bending moments, shear forces and axial actions (F_{eh}) induced by such movements.
NOTE: When using raking piles, vertical ground movements may also cause bending moments and/or shear forces in the pile together with axial actions. Caution should be exercised in such cases.
- (e) Where displacement piles are installed at relatively close spacings, consideration shall be given to vertical and lateral displacements, compression and tensile actions, and bending moments induced in piles that have already been installed. If assessed to be necessary, measures shall be taken to mitigate the above effects.

3.3.1.3 Handling

Stresses induced in a pile by handling during manufacture, transport and on site, as appropriate, shall be determined by taking account of the number and location of lifting points, the mass of the pile and the length of the pile.

The calculated stresses in a pile due to handling shall be multiplied by an appropriate load factor to allow for impact. The minimum load factor for handling shall be 1.5.

The maximum stresses imposed by handling shall not exceed the values given in Clause 7.3.2.

3.3.1.4 Installation

For driven piles, allowance shall be made for the stresses induced during installation.

Compressive and tensile driving stresses may be obtained from a wave-equation analysis or directly measured during pile driving, using dynamic pile testing equipment.

The maximum stresses imposed by driving shall not exceed the values given in Clause 7.3.3.

3.3.2 Load combinations for strength design

The load combinations for strength design shall be as follows:

- (a) The design actions for ultimate strength design of piles shall be the combination of factored loads that produces the most adverse effect on the pile in accordance with AS/NZS 1170.0.
- (b) Where there are actions induced by ground movement (see Clause 3.3.1.2), they shall be computed as follows:
 - (i) *For structural design* (see Section 5)
 - (A) $S_u = 1.2 F_{nf}$ negative friction actions
 - (B) $S_u = 1.5 F_{es}$ compressive and tensile actions
 - (C) $S_u = 1.5 F_{em}$ bending moments, shear forces and axial actions
 - (D) $S_u = 1.5 F_{eh}$ bending moments, shear forces and axial actions
 - (ii) *For geotechnical design* (see Section 4) Loads induced by soil movements shall not be taken into account.

NOTE: The negative friction action (F_{nf}) should be determined with due conservatism, particularly where possible set up and/or time-dependent strain softening are not accounted for explicitly.

- (c) Where other additional actions are to be applied and no load factor is given in AS/NZS 1170.0 for these actions, a load factor of 1.5 shall be assigned.

3.3.3 Load combinations for serviceability design

The design actions for serviceability design of piles shall be taken from the appropriate combinations of actions for short-term situations and long-term situations in accordance with this Clause with the actions as given in AS/NZS 1170.0 and including unfactored actions due to any of the ground movements referred to in Clause 3.3.1.2, as appropriate.

Unless otherwise specified, earthquake serviceability actions need not be taken into account.

SECTION 4 GEOTECHNICAL DESIGN

4.1 GENERAL

The geotechnical design of a pile or pile group involves consideration of both strength and serviceability. The design shall take into account pile-soil interaction.

4.2 ASSESSMENT OF GEOTECHNICAL PARAMETERS

Values of the soil and rock parameters used in design shall be selected, based on the following considerations:

- (a) Geological, hydrogeological and geotechnical background information.
- (b) The possible modes of failure.
- (c) Results of laboratory and field measurements, taking into account the accuracy of the test method used.
- (d) A careful assessment of the range of values that might be encountered.
- (e) The ranges of in situ and imposed stresses likely to be encountered.
- (f) The potential variability of the parameter values.
- (g) The extent of the zone of influence governing the soil behaviour, for the limit state being considered.
- (h) The influence of workmanship on artificially placed or improved soils.
- (i) The effects of construction activities on the properties of the in situ soil.
- (j) Changes in site conditions, such as excavation, filling or groundwater fluctuation.
- (k) The sensitivity of the calculated result to the relevant parameter.

NOTES:

- 1 In general, the value of a geotechnical parameter should be a conservatively assessed value of that parameter. Engineering judgement needs to be exercised in making such an assessment, with geotechnical engineering advice being obtained as required.
- 2 Many soil parameters are not constants, but depend on factors such as the level of stress or strain, the mode of deformation, drainage conditions, and time.
- 3 It should be recognized that a low value of a geotechnical parameter is not always necessarily a conservative value. For example, in cases involving pile driveability, dynamic earthquake loads or negative skin friction and other loads due to ground movements, conservatism may require the selection of a high value of a particular parameter.
- 4 Bending moments in buried structures are sensitive to the relative stiffness of the structure and the surrounding soil. The design should consider variation in the stiffness parameters of both the soil and the structure.
- 5 Except where specifically noted, the term soil includes soil and rock. In many cases, weak weathered rock can be analysed as for soil; however, special techniques may be required for the analysis of strong rock.

4.3 GENERAL PRINCIPLES OF GEOTECHNICAL STRENGTH DESIGN

4.3.1 Design geotechnical strength

A pile shall be proportioned such that the design geotechnical strength ($R_{d,g}$) is not less than the design action effect (E_d) as detailed in Clause 3.2.2, that is—

$$R_{d,g} \geq E_d \quad \dots 4.3.1(1)$$

The design geotechnical strength ($R_{d,g}$) shall be calculated as the design ultimate geotechnical strength ($R_{d,ug}$) multiplied by a geotechnical strength reduction factor (ϕ_g), according to the following equation:

$$R_{d,g} = \phi_g R_{d,ug} \quad \dots 4.3.1(2)$$

The geotechnical strength reduction factor (ϕ_g) shall be determined as follows:

$$\phi_g = \phi_{gb} + (\phi_{tf} - \phi_{gb})K \geq \phi_{gb}$$

where

ϕ_{gb} = basic geotechnical strength reduction factor as given in Clause 4.3.2

ϕ_{tf} = intrinsic test factor

= 0.9, for static load testing (see Section 8)

= 0.75, for rapid load testing (see Section 8)

= 0.8, for dynamic load testing of preformed piles (see Section 8)

= 0.75, for dynamic load testing of other than preformed piles (see Section 8)

= 0.85, for bi-directional load testing (see Section 8)

= ϕ_{gb} , for no testing

K = testing benefit factor

= $1.33p/(p + 3.3) \leq 1$, for static or rapid load testing

= $1.13p/(p + 3.3) \leq 1$, for dynamic load testing

p = percentage of the total piles that are tested and meet the specified acceptance criteria

Where one or more piles tested fail to meet the specified acceptance criteria, the procedure set out in Clause 8.3.4 shall be followed.

NOTES:

- 1 The geotechnical strength reduction factor for dynamic load testing relates to high-strain dynamic pile testing systems that involve direct measurement of strain and acceleration at the pile head, and a signal matching process involving simulation of the measured upward travelling stress wave. Alternative dynamic testing systems may be used, but in such cases a geotechnical strength reduction factor should be adopted based on a demonstration of the uncertainties of those systems relative to the high-strain dynamic testing systems described. In no case shall the geotechnical strength reduction factor adopted be higher than the stipulated value for high strain dynamic testing.
- 2 Where there is a satisfactory correlation between static and dynamic tests, ϕ_{tf} may be increased by 0.05.

4.3.2 Assessment of basic geotechnical strength reduction factor (ϕ_{gb})

The basic geotechnical strength reduction factor (ϕ_{gb}) shall be calculated using a risk assessment procedure as set out below:

- Rate each risk factor in Table 4.3.2(A) on a scale from 1 to 5 for the nature of the site, the available site information and the pile design and installation procedures adopted. This will produce an individual risk rating (IRR) according to the assessed level of risk, as set out in Table 4.3.2(B)
- Determine the overall design average risk rating (ARR) using the weighted average of the product of all of the risk weighting factors (w_i) shown in column 2 of Table 4.3.2(A) times the relevant individual risk rating (IRR), as follows:

$$ARR = \Sigma(w_i IRR_i) / \Sigma w_i \quad \dots 4.3.2$$

- Determine the basic geotechnical strength reduction factor (ϕ_{gb}) from Table 4.3.2(C) depending on the level of redundancy in the piling system. Systems with a high degree of redundancy would include large pile groups under large caps, piled rafts and pile groups with more than 4 piles. Systems with a low level of redundancy would include isolated heavily loaded piles and piles set out at large spacings.

TABLE 4.3.2(A)
WEIGHTING FACTORS AND INDIVIDUAL RISK RATINGS
FOR RISK FACTORS

Risk factor	Weighting factor (w_i)	Typical description of risk circumstances for individual risk rating (IRR)		
		1 (Very low risk)	3 (Moderate)	5 (Very high risk)
Site				
Geological complexity of site	2	Horizontal strata, well-defined soil and rock characteristics	Some variability over site, but without abrupt changes in stratigraphy	Highly variable profile or presence of karstic features or steeply dipping rock levels or faults present on site, or combinations of these
Extent of ground investigation	2	Extensive drilling investigation covering whole site to an adequate depth	Some boreholes extending at least 5 pile diameters below the base of the proposed pile foundation level	Very limited investigation with few shallow boreholes
Amount and quality of geotechnical data	2	Detailed information on strength compressibility of the main strata	CPT probes over full depth of proposed piles or boreholes confirming rock as proposed founding level for piles	Limited amount of simple in situ testing (e.g., SPT) or index tests only
Design				
Experience with similar foundations in similar geological conditions	1	Extensive	Limited	None

(continued)

TABLE 4.3.2(A) (continued)

Risk factor	Weighting factor (w_i)	Typical description of risk circumstances for individual risk rating (IRR)		
		1 (Very low risk)	3 (Moderate)	5 (Very high risk)
Method of assessment of geotechnical parameters for design	2	Based on appropriate laboratory or in situ tests or relevant existing pile load test data	Based on site-specific correlations or on conventional laboratory or in situ testing	Based on non-site-specific correlations with (for example) SPT data
Design method adopted	1	Well-established and soundly based method or methods	Simplified methods with well-established basis	Simple empirical methods or sophisticated methods that are not well established
Method of utilizing results of in situ test data and installation data	2	Design values based on minimum measured values on piles loaded to failure	Design methods based on average values	Design values based on maximum measured values on test piles loaded up only to working load, or indirect measurements used during installation, and not calibrated to static loading tests
Installation				
Level of construction control	2	Detailed with professional geotechnical supervision, construction processes that are well established and relatively straightforward	Limited degree of professional geotechnical involvement in supervision, conventional construction procedures	Very limited or no involvement by designer, construction processes that are not well established or complex
Level of performance monitoring of the supported structure during and after construction	0.5	Detailed measurements of movements and pile loads	Correlation of installed parameters with on-site static load tests carried out in accordance with this Standard	No monitoring

NOTE: The pile design shall include the risk circumstances for each individual risk category and consideration of all of the relevant site and construction factors.

TABLE 4.3.2(B)
INDIVIDUAL RISK RATING (IRR)

Risk level	Individual risk rating (IRR)
Very low	1
Low	2
Moderate	3
High	4
Very high	5

TABLE 4.3.2(C)
BASIC GEOTECHNICAL STRENGTH REDUCTION FACTOR (ϕ_{gb})
FOR AVERAGE RISK RATING

Range of average risk rating (ARR)	Overall risk category	ϕ_{gb} for low redundancy systems	ϕ_{gb} for high redundancy systems
ARR ≤ 1.5	Very low	0.67	0.76
$1.5 < \text{ARR} \leq 2.0$	Very low to low	0.61	0.70
$2.0 < \text{ARR} \leq 2.5$	Low	0.56	0.64
$2.5 < \text{ARR} \leq 3.0$	Low to moderate	0.52	0.60
$3.0 < \text{ARR} \leq 3.5$	Moderate	0.48	0.56
$3.5 < \text{ARR} \leq 4.0$	Moderate to high	0.45	0.53
$4.0 < \text{ARR} \leq 4.5$	High	0.42	0.50
> 4.5	Very high	0.40	0.47

4.3.3 Assessment of design ultimate geotechnical strength ($R_{d,ug}$)

The design ultimate geotechnical strength of a pile ($R_{d,ug}$) shall be assessed by one or more of the following procedures:

- (a) Analysis using data from a site investigation.
- (b) Analysis based on dynamic data obtained during installation of test or working piles, via—
 - (i) a pile driving formula;
 - (ii) a wave equation analysis based on measured blow counts;
 - (iii) a closed form dynamic solution based on measured dynamic force and velocity data; or
 - (iv) analysis based on stress-wave matching of dynamic test data.
- (c) Analysis using data collected during pile installation.
- (d) Analysis using data from a static, rapid or bi-directional load test.

NOTE: Procedures (b) and (c) above are generally applicable for the design ultimate geotechnical strength for axial loading only.

For proprietary piling systems that use indirect correlations with measured pile installation parameters to estimate the ultimate strength of a pile, such correlations shall be supported by appropriate data obtained from static load tests carried out at the site or in-ground conditions that can be demonstrated to be similar to those at the site, in accordance with Section 8.

$R_{d,ug}$ shall be computed as set out in Clauses 4.4.1 to 4.4.7. Consideration shall also be given to the factors in Clauses 4.4.8 to 4.4.10.

4.4 DESIGN REQUIREMENTS FOR STRENGTH

4.4.1 Design ultimate geotechnical strength in compression

The design ultimate geotechnical strength of a pile ($R_{d,ug}$) loaded in compression shall be determined as follows:

$$R_{d,ug} = f_{m,s}A_s + (f_b + p_o)A_b - W \quad \dots 4.4.1(1)$$

NOTE: It is often sufficiently accurate to assume that $W = A_b p_o$ so that Equation 4.4.1(1) becomes—

$$R_{d,ug} = f_{m,s}A_s + f_b A_b \quad \dots 4.4.1(2)$$

In the determination of A_s , in the absence of other data, the surface area from ground surface level to 1.5 pile diameters shall be assumed to be ineffective. For a pile that is to be subjected to cyclic lateral loading, due allowance shall be made in the determination of A_s for the separation that may occur between the pile and the surrounding ground in the vicinity of the ground surface.

In computing A_b , consideration shall be given to the type of pile and the possibility that only a part of the gross cross-sectional area may be effective in providing end-bearing resistance.

In computing both A_s and A_b for steel and concrete screw piles, and for steel tube and H-piles, consideration shall be given to alternative modes of failure of both the shaft and the base.

In assessing $f_{m,s}$ and f_b , consideration shall be given to the pile type, the method of installation, the soil type and other factors which may influence $f_{m,s}$ and f_b , such as the installed condition of the pile shaft and base.

Where a pile is founded on a stratum that overlies a softer or weaker stratum, allowance shall be made for the possible reduction of f_b due to the presence of the softer or weaker stratum.

The possibility of buckling of a pile subjected to compressive loading shall be given consideration when determining the ultimate structural strength as set out in Section 5.

4.4.2 Design ultimate geotechnical strength in uplift

The design ultimate geotechnical strength ($R_{d,ug}$) of a pile loaded in sustained uplift shall be determined as follows:

- (a) For a pile without an enlarged base in soil:

$$R_{d,ug} = f_{m,st} A_s + W \quad \dots 4.4.2(1)$$

- (b) For a pile with an enlarged base in soil, the lesser of—

$$R_{d,ug} = f_{bt} A_b + W ; \text{ and} \quad \dots 4.4.2(2)$$

$$R_{d,ug} = f_{bt} A'_b + f_{m,st} A_s + W \quad \dots 4.4.2(3)$$

In assessing $f_{m,st}$ and f_{bt} , consideration shall be given to the pile type, the method of installation, the soil type, and other factors that may influence $f_{m,st}$ and f_{bt} .

For piles subjected to transient uplift loading, Equations 4.4.1(2) and 4.4.2(3) may be used with an appropriate value of f_{bt} , provided the pile base is embedded in a material of low permeability such that a base suction can develop and be maintained during the duration of the loading.

For a pile in rock or fissured clay, consideration shall be given to the provisions of Items (a) and (b) above, and also to the possibility of failure occurring by pullout of a cone of rock or fissured clay attached to the pile.

NOTES:

- 1 In uplift, the load displacement behaviour is typically more brittle than in compression.
- 2 The cone pullout mode of failure may be critical for shallow piles socketed into rock or fissured clay.
- 3 For piles in sand, very stiff to hard clay or rock, $f_{m,st}$ is often less than $f_{m,s}$ because of the Poisson and other effects.
- 4 For tapered piles, the effect of the taper in further reducing shaft resistance should be considered.
- 5 $R_{d,ug}$ should be computed for both short-term and long-term conditions and the lesser value adopted.

- 6 In assessing shaft friction in uplift ($f_{m,st}$) from dynamic load testing of open-ended steel piles with an internal soil plug, allowance should be made for the proportion of measured shaft resistance that results from internal friction between the pile and the soil plug. In the absence of other information, the shaft resistance over the length of the soil plug should be taken as 0.8 times the measured shaft resistance over that length.

4.4.3 Design ultimate geotechnical strength of a pile group in compression or uplift

4.4.3.1 General

In determining the design ultimate geotechnical strength of a group of piles in compression or uplift, account shall be taken of the effects of group action. In the absence of an alternative method, the design ultimate geotechnical strength shall be taken as the lesser of—

- (a) the sum of the design ultimate geotechnical strength of the individual piles in the group; and
- (b) the design ultimate geotechnical strength of a block containing the piles and the soil between them.

Consideration shall be given to pile type, the method of installation, the soil type, layering of the geotechnical profile, interaction between the piles and the effects of any eccentric and horizontal loadings.

NOTES:

- 1 Eccentric loading is unlikely to adversely affect the ultimate geotechnical strength of a group unless the load eccentricity exceeds about one-quarter of the group width in the direction of the eccentricity.
- 2 The presence of soft or loose layers of soil below the pile toe may have a more significant effect on the ultimate geotechnical strength of a block than on the ultimate geotechnical strength of a single pile.
- 3 Generally, a spacing of less than 2.5 diameters for friction piles is not recommended unless an analysis of interaction effects indicates that overall pile group performance is not adversely affected. For piles deriving their resistance mainly from end-bearing, the spacing should not be less than twice the base size of the pile, unless interaction effects for those groups have been analysed.

Where a group has a cap cast directly onto a stratum supporting the piles, and this stratum is assessed to be unlikely to settle away from the pile cap, it shall be permissible to make allowance for the additional resistance provided by the cap. In the absence of an alternative method, the design ultimate geotechnical strength of the group shall be taken as the lesser of—

- (i) the sum of the design ultimate geotechnical strengths of the individual piles in the group, plus the design ultimate geotechnical strengths of the net area of the pile cap (gross area less the area occupied by the piles); and
- (ii) the design ultimate geotechnical strength of the block containing the piles and the soil between them, plus the design ultimate geotechnical strength of the area of the cap outside the perimeter of this block.

4.4.3.2 End-bearing piles

For a group of end-bearing piles on rock, or on dense sand or gravel with equally strong material beneath, where there is an absence of alternative methods of calculation, the design ultimate geotechnical strength of the group for compressive axial loading shall be taken as the sum of the design ultimate geotechnical strengths of the individual piles in the group.

4.4.3.3 *Soft material at depth*

Where a pile group is founded on a stratum that overlies a softer or weaker stratum, allowance shall be made for the possible reduction in ultimate base resistance due to the presence of the softer or weaker underlying stratum.

4.4.4 Combined pile and raft foundation

Piles may be used to provide additional support beneath a raft foundation in order to control total and differential settlements. The design of such a combined foundation shall satisfy—

- (a) the geotechnical strength criterion in Clause 4.3.1; and
- (b) the serviceability criterion in Clause 4.5.

The design ultimate geotechnical strength of the combined pile and raft foundation ($R_{d,ug,c}$) shall be calculated as follows:

$$R_{d,ug,c} = \phi_{gs}R_{d,ug,s} + \phi_g R_{d,ug} \quad \dots 4.4.4$$

$R_{d,ug,s}$ shall be computed by means of an appropriate analysis, using the results of suitable field and/or laboratory tests.

The value of ϕ_{gs} shall be selected from the values of ϕ_g in Clause 4.3 for static analysis, taking into account the relevant risk factors for the raft only.

The value of $R_{d,ug}$ shall be computed as set out in Clause 4.4.1.

The value of ϕ_g shall be chosen as set out in Clause 4.3.

NOTE: Where the stratum beneath the raft is assessed to be likely to settle away from the raft, the settlement required to mobilize $R_{d,ug,s}$ may be very large, and the serviceability criterion may be critical.

4.4.5 Negative friction

Consideration shall be given to whether pile-ground contact friction resistance from settling ground can be relied upon in determining the design ultimate geotechnical resistance for ultimate limit state design.

In the absence of other information, the design ultimate geotechnical strength of the pile in compression or in uplift shall be assumed to be unaffected by negative friction and shall be computed as set out in Clauses 4.4.1 and 4.4.2 for a single pile, Clause 4.4.3 for a pile group, and Clause 4.4.4 for a combined pile raft foundation.

NOTE: The pile-ground contact friction resistance may be reduced for piles with a tapered shaft.

The additional axial forces induced in a pile by negative friction shall be considered in the structural design of the pile.

The settlement of a pile or pile group subjected to negative friction is often the key design consideration and shall be assessed as set out in Clause 4.6.3.

NOTE: Appropriate surface coatings may be applied to the part of the pile shaft in the settling ground zone to reduce negative skin friction.

4.4.6 Soil swelling

In the absence of other information, the design ultimate geotechnical strength of a pile in compression or uplift shall be assumed to be unaffected by swelling of the soil around the pile.

The additional axial forces induced in a pile by soil swelling shall be considered in the structural design of the pile.

The head movement of a pile subjected to soil swelling shall be assessed as set out in Clause 4.6.4.

NOTE: Where swelling of the soil surrounding a pile is expected to occur after installation and the pile is under uplift loading, the ultimate geotechnical resistance may not be mobilized until large upward movements of the pile head have occurred under applied loading.

4.4.7 Design ultimate geotechnical strength for lateral loading

For a pile subjected to lateral loading, its design ultimate geotechnical strength shall be determined as the lesser of the following two values:

- (a) The design ultimate geotechnical strength for ‘short pile’ failure, in which the ultimate lateral resistance of the soil surrounding the pile is fully mobilized along the entire length of the pile.
- (b) The design ultimate geotechnical strength for ‘long pile’ failure, in which the ultimate structural strength of the pile section at some point along the pile shaft is fully mobilized before the ultimate soil resistance along the entire length of the pile.

For a pile group, in the absence of an alternative method, the design ultimate geotechnical strength shall be taken as the lesser of the following values:

- (i) The sum of the design ultimate geotechnical strength of the individual piles in the group.
- (ii) The design ultimate geotechnical strength of a block containing the piles and the soil between them.

Consideration shall be given also to the possibility that the near-surface soil may have reduced lateral resistance because of environmental effects. For a pile that is to be subjected to cyclic lateral loading, consideration shall be given to the possibility that separation may occur between the pile and the surrounding ground in the vicinity of the ground surface.

Consideration shall be given to pile type, the method of installation, the soil type, layering of the geotechnical profile, interaction among the piles and the effects of any eccentric loading.

4.4.8 Cyclic loading

Consideration shall be given to the effects of cyclic loading on the axial and lateral design ultimate geotechnical strengths of both a single pile and a pile group.

Consideration shall be given also to the possibility that the near-surface soil may have a reduced axial and lateral resistance because of environmental effects and that separation may occur between the pile and the surrounding ground in the vicinity of the ground surface.

In particular, appropriate caution shall be exercised in assessing the design ultimate geotechnical strength of both a pile and a pile group subjected to cyclic uplift loading or to ‘two-way’ cyclic axial loading involving both compressive and uplift loading, or to a loading regime that leads to cyclic reversals in sign of the shear stress over all or part of the pile-soil interface.

4.4.9 Dynamic loading

Consideration shall be given to the effects of dynamic loading on the axial and lateral ultimate geotechnical strengths of a pile.

NOTE: In some cases, the high rate of dynamic loading may increase the geotechnical strength as compared to the case of static loading.