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AS 2159—1995

Australian Standard®

Piling—Design and installation

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The following interests are represented on Committee CE/18:

Australian Building Codes Board

Australian Construction Services, Department of Administrative Services

Australian Geomechanics Society

AUSTROADS

Institution of Engineers, Australia

Maritime Services Board of New South Wales

Monash University

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PREFACE

This Standard has been produced by the Standards Australia Committee CE/18 on Piling, and supersedes AS 2159—1978, *Rules for the design and installation of piling (known as the SAA Piling Code)*.

This Standard has been prepared because of a growing perception within the user community that the earlier document was becoming outdated and also that, in common with other modern structural codes, the Piling Code should appear in limit state format.

It was also considered that the material should be in two parts, viz. a Code of Practice which presents mandatory rules for the design, installation and testing of piled footings and guidelines which provide additional information and recommendations in relation to the Code of Practice.

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CONTENTS

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Page

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FOREWORD

Since piling is a field in which design formulae, rules of thumb, the lessons of experience, and the accumulated records of a large number of applications of proprietary systems, both successful and otherwise, can influence decision-making, there is a great need for flexibility, wide experience 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 will be seen to be short and simple when, in other cases, extensive arrays of multiple choices will be required. Where applicable, explanatory notes are added to some clauses in this Standard.

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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, or to detached Class 1 building as defined in the Building Code of Australia.

NOTES:

1 AUSTROADS Bridge Design Code should be considered for the design of footings for road bridges.

2 The date of application of the Standard on a mandatory basis is matter for the relevant authority. AS 2159—1978 will be withdrawn following substantial regulatory implementation of this edition, or within two years of publication of this edition, whichever is the earlier.

1.2 APPLICATION The Standard is intended for use by designers, constructors and regulatory bodies in executing their responsibilities in relation to piling in civil engineering and building.

1.3 REFERENCED DOCUMENTS The following documents are referred to in this Standard:

AS

1012 Methods of testing concrete (all Parts)

1163 Structural steel hollow sections

1170 Minimum design loads on structures (known as the SAA Loading Code)
1170.1 Part 1: Dead and live loads and load combinations
1170.2 Part 2: Wind loads
1170.3 Part 3: Snow loads
1170.4 Part 4: Earthquake loads

1302 Steel reinforcing bars for concrete

1379 The specification and manufacture of concrete

1450 Steel tubes for mechanical purposes

1554 Structural steel welding (known as the SAA Structural Steel Welding Code)

1579 Arc welded steel pipes and fittings for water and waste water

1604 Timber—Preservative-treated—Sawn and round

1720 Timber structures (known as the SAA Timber Structures Code)
1720.1 Part 1: Design methods

1726 Geotechnical site investigations

2209 Timber—Poles for overhead lines

2701 Methods of sampling and testing mortar for masonry constructions
2701.2 Method 2: Methods of sampling

2832 Guide to the cathodic protection of metals
2832.2 Part 2: Compact buried structures
2832.3 Part 3: Fixed immersed structures

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AS
3600 Concrete structures
3678 Structural steel—Hot-rolled plates, floor-plates and slabs
3679 Structural Steel
3679.1 Part 1: Hot-rolled bars and sections
3679.2 Part 2: Welded sections
3735 Concrete structures for retaining liquids
3972 Portland and blended cements
4100 Steel structures

AS/NZS
2312 Guide to the protection of iron and steel against exterior atmospheric corrosion

ASTM
C 566-89 Test method for total moisture content of aggregate by drying

AUSTROADS Bridge Design Code

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

1.4.1 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.

1.4.2 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.

1.4.3 Characteristic strength—that value of the material strength, as assessed by a standard test, which is exceeded by 95 percent of the material.

1.4.4 Cone penetration test (CPT)—as defined in AS 1726.

1.4.5 Continuous flight auger pile (CFA)—a pile formed in the ground by drilling with a hollow flight auger which is subsequently and progressively withdrawn, with the cavity below the auger tip being gradually filled with concrete or cement grout injected under pressure.

1.4.6 Design action—the combination of the nominal loads, other actions and the load factors, as specified in AS 1170.1 or AS 1170.2, or AS 1170.3.

1.4.7 Design action effect-S^*—the action or load effect computed from the design actions or design loads.

1.4.8 Design geotechnical strength R^*_g—the product of the ultimate geotechnical strength, R_{ug}, and the geotechnical strength reduction factor, ϕ_g.

1.4.9 Design serviceability load—the load on a pile corresponding to the serviceability limit state.

1.4.10 Design structural strength R^*_s—the product of the ultimate structural strength, R_{us}, and the structural strength reduction factor, ϕ_s.

1.4.11 Driven cast-in-place pile—a pile formed by driving a liner, which is either permanent or temporary and filled with plain or reinforced concrete.

1.4.12 Driven preformed pile—a prefabricated pile installed in the ground by driving.

1.4.13 Durability—measure of the capacity of the structure to withstand deterioration throughout the intended life.

1.4.14 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.

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

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1.4.16 Foundation—the soil, subsoil or rock, whether built-up or natural, upon which a structure is supported.

1.4.17 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.

1.4.18 Ground anchor—a tendon anchored into the ground by bond and used to provide a reaction for test loading piles.

1.4.19 Limit state—the state where the structure or part of the structure fails to satisfy one of its performance criteria. Each limit state is considered separately and its occurrence is either eliminated or shown to be sufficiently improbable.

1.4.20 Pile—a structural member that is driven, screwed, jacked, vibrated, drilled or otherwise installed in the ground so as to transmit loads to the soil or rock.

1.4.21 Pile group—a number of piles installed in close proximity and usually having a common pile cap.

1.4.22 Pile head—the top of a pile.

1.4.23 Pile heave—displacement (vertical or lateral) of a pile caused by the driving or by external ground movements of piles in close proximity.

1.4.24 Professional engineer—a person who is—

(a) if legislation is applicable, a registered professional engineer in the relevant discipline who has appropriate experience and competence in the relevant field; or

(b) if legislation is not applicable—

  (i) a corporate member of the Institution of Engineers, Australia or;

  (ii) eligible to become a corporate member of the Institution of Engineers, Australia, and has appropriate experience and competence in the relevant field.

1.4.25 Raking pile—a pile installed at an angle to the vertical.

1.4.26 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.

1.4.27 Set—the permanent penetration of a driven pile or liner per blow of the hammer.

1.4.28 Standard penetration test (SPT)—as defined in AS 1726.

1.4.29 Temporary compression—the temporary pile-head deflection during a hammer-blow comprising elastic deflection of the helmet components, pile and soil quake.

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

1.4.31 Toe—the base of the pile.

1.4.32 Ultimate geotechnical strength (R_{ug})—the total 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.

1.4.33 Ultimate structural strength (R_{us})—the limit state at which static equilibrium is lost, or at which structural elements fail.

1.5 NOTATION The quantity symbols used in this Standard are listed below.

Unless a contrary indication appears elsewhere, the symbols used in this Standard shall have the meanings below.

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Symbol	Term	Text reference (Clauses)
A_b	Plan area of pile base	4.3.1, 4.3.2
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	4.3.2
A_g	Gross area of pile cross-section	5.3.4, 5.3.5
A_s	Surface area of pile in intimate contact with soil	4.2.4, 4.3.1, 4.3.2
A_{sc}	Cross-sectional area of compression reinforcement	5.3.4(b)
d	Pile diameter	5.6.4(b), Figure 5.1
D_d	Dowel diameter	5.6.4(b), Table 5.3, Figure 5.1
D	Overall width of pile in plane of bending (taken as the pile diameter at mid-length for circular piles)	5.2.2(b)
F_{em}	Bending moments, shear forces and axial loads induced by lateral soil movements	3.3.1.2(c), 3.3.2(b)
F_{es}	Compressive and tensile loads in the pile induced by vertical soil movements	3.3.1.2(b), 3.3.2(b)
F_{nf}	Pile load due to negative friction	3.3.1.2(a), 3.3.2(b)
f_b	Ultimate base pressure for compression pile	4.3.1
f_{bt}	Ultimate base pressure for uplift pile	4.3.2
f'_c	Characteristic concrete strength	5.3.5, Table 6.2
f'_{cm}	Characteristic strength of concrete at relevant age	7.3.3.1(a)
$\bar{f}_s$	Average skin friction for condition of full mobilization—compression pile	4.3.1
$\bar{f}_{st}$	Average skin friction for condition of full mobilization — tension pile	4.3.2
f_{sy}	Yield stress for reinforcement in concrete piles	5.3.4(b), 7.3.3.1(b),
h	Depth to cut-off	7.2.1(b)
k	Modification factor applied to strength of a timber pile	5.6.1
l_1	Minimum edge distance to end of pile	5.6.4(b)
M^*	Design bending moment	5.2.2
N^*	Design axial load	5.2.2(b), 5.3.4(b)
p_o	Total overburden pressure at base level	4.3.1
R^*_g	Design geotechnical strength of pile	1.4.8, 3.2.2(c), 4.2.1, 4.2.2, 4.3.4
R^*_s	Design structural strength of pile	1.4.10, 3.2.2(c), 5.2.1
R_{us}	Ultimate structural strength of pile	1.4.10, 3.2.2(d), 5.2.1, 5.3.1
R_{ug}	Ultimate geotechnical strength of pile (ultimate load capacity)	1.4.8, 1.4.31, 3.2.2(d), 4.2.2, 4.2.4, 4.3.1, 4.3.2, 4.3.4
R_{ugs}	Ultimate geotechnical strength of shallow or raft footing	4.3.4
S^*	Design action effect	1.4.7, 3.2.2(b), 3.2.2(d), 4.2.1, 5.2.1, 8.3.5.2, 8.4.3, 8.4.5, Table 8.1, Table 8.2
W	Weight of pile	4.3.1, 4.3.2
ϕ_g	Geotechnical strength reduction factor for single piles or pile groups	1.4.8, 3.2.2(d), 4.2.2, 4.2.3, 4.3.4, Table 4.1, 4.2
ϕ_{gs}	Geotechnical strength reduction factor for the shallow or raft footing	4.3.4
ϕ_s	Structural strength reduction factor for single piles or pile groups	1.4.10, 3.2.2(d), 5.2.1, 5.3.5, Table 5.2

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1.6 CLASSIFICATION OF PILES

1.6.1 General The classification of pile types used in this Standard is illustrated in Figure 1.1. 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.

1.6.2 Displacement piles Displacement piles are defined as those which 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 which 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* Piles 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.

1.6.3 Non-displacement piles

1.6.3.1 *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.

1.6.3.2 *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.

1.6.3.3 *Unsupported* This classification refers to piles in which the ground is left exposed during excavation.

1.6.4 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.

NOTE: Driven cast-in-place piles with an end plate which is more than 10% greater in diameter than the liner should also be treated as partial displacement piles.

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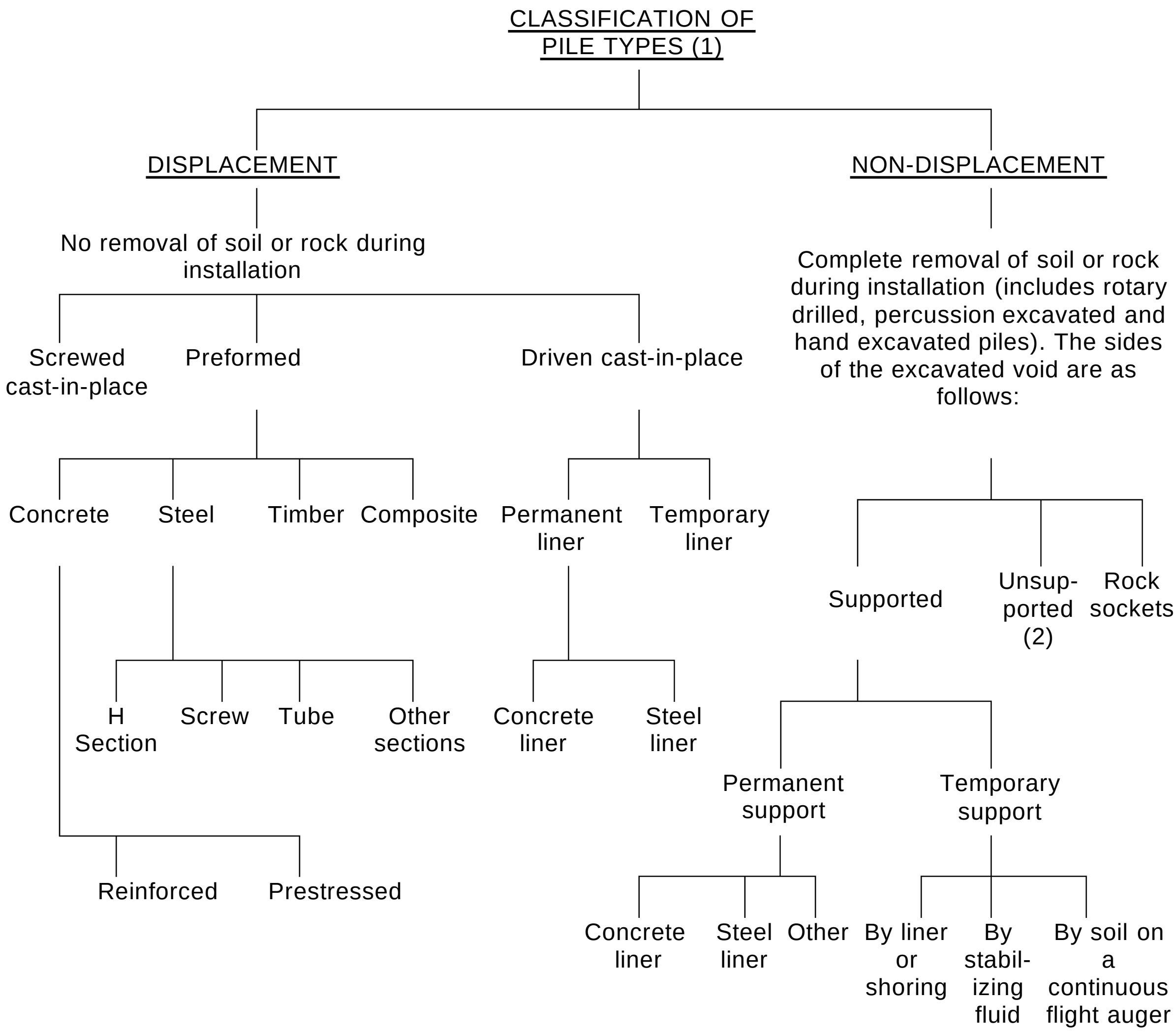
1.7 USE OF ALTERNATIVE MATERIALS OR METHODS

1.7.1 General Provided that the requirements of Section 3 are met, this Standard shall not be interpreted such that it prevents the use of materials or methods of design or construction not specifically referred to.

1.7.2 Existing structures Where the strength or serviceability of an existing structure is to be evaluated, the general principles of this Standard shall be applied. The actual properties of the materials in the structure shall be used.



NOTES:

1 Pile types for which there is no established experience may not fall into these categories.

2 Unsupported. This classification refers to piles in which the ground is left exposed during excavation.

FIGURE 1.1 CLASSIFICATION OF PILE TYPES

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SECTION 2 SITE INVESTIGATIONS

2.1 SITE INVESTIGATION 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.

NOTE: The intention of this Section is to ensure that adequate information is available for design and construction. Where there is already existing information available, further site specific investigation or testing may not be required.

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 include—

(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) negative friction effects;

(vi) near surface conditions or lateral load design, if relevant;

(vii) possible obstructions to installation, e.g. boulders or old footings or piles;

(viii) potential for slope instability; and

(ix) effects of excavation or scour.

(d) Assessment of the potential effects of site conditions on pile durability.

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SECTION 3 DESIGN REQUIREMENTS AND PROCEDURES

3.1 AIM The aim of pile design is to provide a footing which will safely support the superstructure over its design life. 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.

3.2 DESIGN REQUIREMENTS

3.2.1 General 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) *Others* Other relevant design requirements.

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 (S^*) determined for each pile or pile group for each load case.

(c) The design geotechnical strength R^*_g and the design structural strength R^*_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, i.e.

$$R^*_g \geq S^* \text{ and} \quad \ldots (3.1)$$

$$R^*_s \geq S^* \quad \ldots (3.2)$$

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 be taken as the design strength of the sum of the individual piles or the design strength of the group as a single unit, whichever is the lesser.

The design for ultimate strength stated above applies to a situation in which the piles in a pile group are designed to carry loads without any individual pile exceeding its geotechnical design strength. However, it is permissible to allow for the sharing of a load between piles and pile caps or for the sharing of a load between piles, provided that an analysis demonstrates that the complete pile system operates within the general principles of this Standard even though individual piles may not.

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3.2.3 Design for serviceability Single piles and pile groups shall be designed for serviceability by controlling or limiting pile movements.

Under the load combinations for serviceability design determined from Clause 3.3.3, pile movements shall be limited 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 LOADS AND LOAD COMBINATIONS FOR STRENGTH AND SERVICEABILITY DESIGN

3.3.1 Loads and other actions

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 loads and other actions specified in AS 1170.1.

(b) Dead loads of pile and pile cap.

(c) Soil movement, negative friction, expansive soils, and earth movements.

(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 *Soil movement* Allowance shall be made for loads induced by soil movements as follows:

(a) Where a pile is situated in soil undergoing settlement, allowance shall be made for loads F_{nf}, due to negative friction acting on the pile.

(b) Where a pile is situated in expansive soils, such as reactive clays or those subjected to frost action, allowance shall be made for the compressive and tensile loads, F_{es}, which 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 loads, F_{em}, induced by such movements.

(d) Heave due to unloading of soft or other ground due to excavation.

NOTE: When using raking piles, vertical ground movements may also cause bending moments or shear forces in the pile together with axial forces.

3.3.1.3 *Handling* Loads 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.

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.

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3.3.2 Load combinations for strength design The load combinations for strength design shall be as follows:

(a) The design load for ultimate strength design of piles shall be the combination of factored loads which produces the most adverse effect on the pile in accordance with AS 1170.1.

(b) If there are loads induced by soil movement (see Clause 3.3.1.2), they shall be computed as follows:

(i) *Design structural strength* (see Clause 4.3.5)—determined as follows:

(A) 1.2 F_{nf}—negative friction loads.

(B) 1.5 F_{es}—compressive and tensile loads.

(C) 1.5 F_{em}—bending moments, shear forces and axial loads.

(ii) *Design geotechnical strength*—loads induced by soil movement shall not be taken into account.

(c) Where other additional loads and actions are to be applied and no load factor is given in AS 1170.1 for these loads and actions, an appropriate factor shall be adopted or alternatively assign a factor of 1.5.

NOTE: Large pile movements may be required to reach the ultimate capacity of piles subjected to soil induced loadings as described in Clause 3.3.1.2. The serviceability limit state will frequently be the governing criteria for piles in this loading condition.

3.3.3 Load combinations for serviceability design The design loads for serviceability design of piles shall be taken from the appropriate combination of factored loads for short-term effects and long-term effects in accordance with AS 1170.1 and including unfactored loads due to any of the soil movements referred to in Clause 3.3.1.2, as appropriate.

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SECTION 4 GEOTECHNICAL DESIGN

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

4.2 GENERAL PRINCIPLES OF GEOTECHNICAL STRENGTH DESIGN

4.2.1 Design geotechnical strength A pile shall be proportioned such that the design geotechnical strength R^*_g is not less than the design action effect S^* as detailed in Clause 3.2.2, such that:

$$R^*_g \geq S^* \qquad \ldots (4.1)$$

The design geotechnical strength R^*_g shall be calculated as the ultimate geotechnical strength R_{ug} multiplied by a geotechnical strength reduction factor ϕ_g, according to the following equation:

$$R^*_g = \phi_g R_{ug} \qquad \ldots (4.2)$$

4.2.2 Assessment of geotechnical strength reduction factor (ϕ_g) The factor ϕ_g shall be chosen, taking into account the factors which may influence the reliability of the ultimate geotechnical strength. A range of values is given in Table 4.1. Values of ϕ_g in excess of the given ranges shall only be used in exceptional circumstances backed by detailed quantitative justification.

In assessing the value to be chosen within the ranges specified, consideration shall be given to the factors shown in Table 4.2, and appropriate judgement shall be exercised.

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

(a) Static analysis using data from a site investigation.

(b) Static analysis using data from a static test loading.

(c) Static analysis using data from dynamic pile testing.

(d) Dynamic analysis using data obtained during installation of test or working piles, via—

  (i) a wave equation analysis;

  (ii) an appropriate pile driving formula; or

  (iii) a closed-form dynamic solution.

R_{ug} shall be computed as set out in Clauses 4.3.1 to 4.3.7. Consideration shall also be given to the factors in Clauses 4.3.8 to 4.3.10.

In the determination of A_s, in the absence of other data, the surface area from ground surface level to 1.5 pile diameters or 1 m below ground surface level (whichever is the greater) shall be assumed to be ineffective. For a pile which is to be subjected to cyclic lateral loadings, due allowance shall be made, in the determination of A_s, for the separation which may occur between the pile and the surrounding ground in the vicinity of the ground surface.

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

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TABLE 4.1

RANGE OF VALUES FOR GEOTECHNICAL STRENGTH REDUCTION FACTOR ϕ_g

Method of assessment of ultimate geotechnical strength	Range of values of ϕ_g
Static load testing to failure	0.70–0.90
Static proof (not to failure) load testing (NOTE 1)	0.7–0.90
Dynamic load testing to failure supported by signal matching (NOTE 2)	0.65–0.85
Dynamic load testing to failure not supported by signal matching	0.50–0.70
Dynamic proof (not to failure) load testing supported by signal matching (NOTES 1 and 2)	0.65–0.85
Dynamic proof (not to failure) load testing not supported by signal matching (NOTE 1)	0.50–0.70
Static analysis using CPT data	0.45–0.65
Static analysis using SPT data in cohesionless soils	0.40–0.55
Static analysis using laboratory data for cohesive soils	0.45–0.55
Dynamic analysis using wave equation method	0.45–0.55
Dynamic analysis using driving formulae for piles in rock	0.50–0.65
Dynamic analysis using driving formulae for piles in sand	0.45–0.55
Dynamic analysis using driving formulae for piles in clay	Note 2
Measurement during installation of proprietary displacement piles, using well established in-house formulae	0.50–0.65

NOTES:

1 ϕ_g should be applied to the maximum load applied.

2 Signal matching of the recorded data obtained from dynamic load testing should be undertaken on representative test piles using a full wave signal matching process.

3 Caution should be exercised in the sole use of dynamic formulae (e.g. Hiley) for the determination of the ultimate geotechnical strength of piles in clays. In particular, the dynamic measurements will not measure the ‘set-up’ which occurs after completion of driving. It is preferable that assessment be first made by other methods, with correlation then made with dynamic methods on a site-specific basis if these latter are to be used for site driving control.

4 For cases not covered in Table 4.1, values of ϕ_g should be chosen using the stated values as a guide.

TABLE 4.2

GUIDE FOR ASSESSMENT OF GEOTECHNICAL STRENGTH REDUCTION FACTOR (ϕ_g)

Circumstances in which lower end of range may be appropriate	Circumstances in which upper end of range may be appropriate
Limited site investigation	Comprehensive site investigation
Simple method of calculation	More sophisticated design method
Average geotechnical properties used	Geotechnical properties chosen conservatively
Use of published correlations for design parameters	Use of site-specific correlations for design parameters
Limited construction control	Careful construction control
Less than 3% piles dynamically tested	15% or more piles dynamically tested
Less than 1% piles statically tested	3% or more piles statically tested

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4.3 DETAILED DESIGN REQUIREMENTS FOR STRENGTH

4.3.1 Ultimate geotechnical strength in compression The ultimate geotechnical strength of a pile loaded in compression shall be determined from the equation:

$$R_{ug} = \bar{f}_s A_s + (f_b + p_o) A_b - W \quad \ldots 4.3$$

NOTE: It is usually sufficiently accurate to assume that $W = A_b\, p_o$ so that Equation 4.3 becomes:

$$R_{ug} = \bar{f}_s A_s + f_b A_b \quad \ldots 4.4$$

In assessing $\bar{f}_s$ and f_b, consideration shall be given to the pile type, the method of installation, the soil type, and other factors which may influence $\bar{f}_s$ and f_b.

Where a pile is founded on a stratum which 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 in determining the ultimate structural strength, as set out in Section 5.

4.3.2 Ultimate geotechnical strength in uplift The ultimate geotechnical strength of a pile loaded in tension shall be determined as follows:

(a) For a pile without an enlarged base in soil—

$$R_{ug} = \bar{f}_{st} A_s + W \quad \ldots 4.5$$

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

(i) $R_{ug} = f_{bt} A_b + W$ . . . 4.6

and

(ii) $R_{ug} = f_{bt} A'_b + \bar{f}_{st} A_s + W$ . . . 4.7

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

For a pile in rock, 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 attached to the pile. It should be noted that this mode may be critical for shallow piles socketed into jointed rock.

4.3.3 Ultimate geotechnical strength of a pile group in compression or uplift

4.3.3.1 *General* In determining the 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 ultimate geotechnical strength shall be taken as the lesser of—

(a) the sum of the ultimate geotechnical strength of the individual piles in the group; and

(b) the 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 loading.

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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 Typically, 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 ultimate geotechnical strength of the group shall be taken as the lesser of—

(i) the sum of the ultimate geotechnical strengths of the individual piles in the group, plus the ultimate geotechnical strengths of the net area of the pile cap (gross area less the area occupied by the piles); and

(ii) the ultimate geotechnical strength of the block containing the piles and the soil between them, plus the ultimate geotechnical strength of the area of the cap outside the perimeter of this block.

4.3.3.2 *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 ultimate geotechnical strength of the group for compressive axial loading shall be taken as the sum of the ultimate geotechnical strengths of the individual piles in the group.

4.3.3.3 *Soft material at depth* Where a pile group is founded on a stratum which overlies a softer stratum, allowance shall be made for the possible reduction in ultimate base resistance due to the presence of the softer underlying stratum.

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

(a) the geotechnical strength criterion in Clause 4.2.1; and

(b) the serviceability criterion in Clause 4.4.

The geotechnical design strength R_g^* of the combined footing shall be calculated as follows:

$$R_g^* = \phi_{gs} R_{ugs} + \phi_g R_{ug} \qquad \text{. . . (4.8)}$$

R_{ugs} shall be computed by means of an appropriate analysis, using the results of suitable field and laboratory tests.

The value of ϕ_{gs} shall be selected from the values of ϕ_g in Table 4.1 for static analysis.

The value of R_{ug} shall be computed as set out in Clause 4.3.1.

The value of ϕ_g shall be chosen from Table 4.1 as set out in Clause 4.2.3.

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

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4.3.5 Negative friction In the absence of other information, the ultimate geotechnical strength in compression or uplift shall be assumed to be unaffected by negative friction and shall be computed as set out in Clauses 4.3.1 and 4.3.2 for a single pile, and Clause 4.3.3 for a pile group.

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 subjected to negative friction shall be assessed as set out in Clause 4.5.3.

NOTES:

1 Where settlement of the soil surrounding a pile is expected to occur after installation, and the pile is under compressive loading, the ultimate geotechnical resistance may not be mobilized until a very large settlement of the pile head has occurred under applied loading.

2 Use of appropriate surface coatings applied to the pile shaft may largely reduce negative skin friction.

4.3.6 Soil swelling In the absence of other information, the 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 4.5.4.

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.

4.3.7 Ultimate geotechnical strength for lateral loading For a pile subjected to lateral loading, its ultimate geotechnical strength shall be determined as the lesser of the following two values—

(a) the 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; and

(b) the 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, the ultimate geotechnical strength shall be determined as set out in Clause 4.3.3.1.

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

In particular, appropriate caution shall be exercised in assessing the ultimate axial 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.

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

4.3.10 Earthquake loading Consideration shall be given to the effects of earthquake loading on the axial and lateral ultimate geotechnical strengths, and to the induced bending moment in a pile by lateral ground movements. A pile shall be designed for adequate strength, stiffness and ductility under load combinations including earthquake design actions.

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4.4 GENERAL PRINCIPLES OF GEOTECHNICAL DESIGN FOR SERVICEABILITY

4.4.1 Design actions The load combinations for serviceability design, as determined from Clause 3.3.3, shall be used for determining pile deflection (settlements, lateral deflections and rotations).

4.4.2 Design criteria Both a single pile and a pile group shall be designed for serviceability by controlling or limiting pile movements so that deflections do not exceed the deflection limits.

4.4.3 Deflection limits Limits for the total and differential settlement, lateral deflection and rotation of both a pile and a pile group, subject to axial compression, uplift, lateral, cyclic, dynamic, torsional or other actions, shall be appropriate to the structure and its intended use.

4.4.4 Geotechnical parameters, for serviceability limit states Calculations of settlement, differential settlement, lateral deflection and rotation of both a pile and a pile group shall be carried out using geotechnical parameters which are appropriately selected and to which no reduction factor is applied.

4.5 DETAILED DESIGN REQUIREMENTS FOR SERVICEABILITY

4.5.1 Deflection of a pile Settlements, lateral deflections and rotations shall be estimated by calculation or assessed from a load test. Account shall be taken of group action, the influence of any underlying compressible layers, variable stiffness of individual strata, and any other site-specific conditions.

In assessing the deflection and differential settlement of a structure supported by piles, consideration shall be given to the effects of the stiffness of the structure.

4.5.2 Combined pile and raft footing Where a footing is designed as a combined pile and raft footing, the settlements and differential settlement of the footing shall be estimated from an analysis in which account is taken of the interaction between the raft, the piles and the soil.

4.5.3 Settlement due to negative friction Consideration shall be given to the settlement of both a pile and a pile group resulting from negative friction, i.e. effects caused by settlement of the surrounding ground.

NOTE: In the absence of an analysis in which pile-soil interaction is allowed for, the settlement of a pile or pile group subjected to negative friction may be approximated as the greater of the following:

(a) The settlement of the ground at the ‘neutral point’ in the ground, that is the depth at which the shaft friction on the pile changes from negative (downward) to positive (upward). Applied compressive loading tends to raise the ‘neutral point’ and increase the settlement of the pile or pile group.

(b) The sum of the following three components—

  (i) the compression of the pile shaft due to the design action;

  (ii) the compression of the pile shaft due to the computed forces arising from negative friction; and

  (iii) the settlement of the portion of the pile shaft in the ‘stable’ soil (the part of the soil profile not subjected to movement) under the sum of the design action and the maximum computed force in the pile arising from negative friction.

4.5.4 Pile heave due to soil swelling Consideration shall be given to the heave of both a pile and a pile group resulting from negative swelling movements of the surrounding ground.

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NOTE: In the absence of an analysis in which pile-soil interaction is allowed for, the heave of a pile or pile group subjected to soil swelling may be approximated by the greater of the following:

(a) The heave of the ground at the 'neutral point' in the ground, that is, the depth at which the shaft friction on the pile changes from positive (upward) to negative (downward). Applied uplift loading tends to raise the 'neutral point' and increase the heave of the pile or pile group.

(b) The sum of the following three components—

(i) the extension or compression of the pile shaft due to the design action;

(ii) the extension of the pile shaft due to the computed forces arising from soil swelling; and

(iii) the upward movement of the portion of the pile shaft in the 'stable' soil (that part of the soil profile not subjected to swelling) under the design action and the maximum computed force in the pile arising from soil swelling.

4.5.5 Deflection due to cyclic, dynamic and torsional or other loads Where a pile or pile group is subjected to cyclic, impact, dynamic, earthquake, torsional or other loads, deflections and rotations shall be estimated by calculation or assessed from an appropriate load test.

Reference shall be made to AS 1170.4 for an assessment of earthquake risk sites within Australia.

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SECTION 5 STRUCTURAL DESIGN

5.1 SCOPE The design structural strength of a pile shall comply with this Section. This Section details ultimate structural strength requirements. Structural serviceability requirements are incorporated within the scope of Section 4.

5.2 GENERAL PRINCIPLES OF STRUCTURAL STRENGTH DESIGN

5.2.1 Design structural strength A pile shall be proportioned such that its design structural strength is not less than the design action effect S^* as detailed in Clause 3.2.2 i.e. $R^*_s \geq S^*$.

The design structural strength R^*_s shall be calculated as the ultimate structural strength R_{us} multiplied by a structural strength reduction factor ϕ_s according to the equation as follows:

$$R^*_s = \phi_s R_{us} \qquad \ldots (5.1)$$

and in accordance with Clauses 5.3.1, 5.4 and 5.6, below.

5.2.2 Design bending moment (M^*) In addition to other relevant design action effects, a pile shall be designed for the greater of Item (a) or Item (b), as follows:

(a) The sum of—

(i) the moment at any section caused by the load combination for strength design in Clause 3.3.2; and

(ii) the moment generated in a pile caused by the out-of-position tolerance given in Clause 7.2.1 and other specified tolerance or measured displacement from the design location.

(b) A moment about each principal axis of N^* times $0.05D$ where N^* is the design axial load on a cross-section and D is the overall width of the pile in the plane of the bending moment.

NOTES:

1 The moment due to out-of-position location should preferably be calculated by a rigorous structural analysis of the pile or pile group and the above structure, taking relative stiffness of the pile and beam or slab and fixity between the members into account.

In the absence of such an analysis, the design moment at the head of the pile for a single pile and groups of two or more piles in one line should not be less than the following:

(a) Single pile = N^* times the pile tolerance in any direction.

(b) Two pile group = N^* times the pile tolerance on an axis perpendicular to the line of the pile.

2 Where the pile cap, beam or slab arrangement above the pile are very stiff compared with the pile, or where piles are in groups of three or more, it may be apparent that out-of-position tolerance moments generated within the piles are small without the necessity for a rigorous structural analysis.

5.2.3 Buckling of a pile Where a pile has a freestanding portion above ground level or is installed in very soft soils, consideration shall be given to the possibility of buckling in the determination of the pile strength in compression and bending.

5.2.4 Pile splice A performed pile may be spliced provided that the pile splice is designed for the following:

(a) *The design loads and other actions at the splice level* In determining the design loads and other actions, the final splice position shall be taken into account and, unless it can be shown that the splice will be located at a known level, it shall be designed for the maximum design action effect in the section.

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(b) *Pile driving stresses* The effects of transmission of the driving stress waves and any tension stresses generated during driving shall be taken into account.

5.3 CONCRETE AND GROUT PILES

5.3.1 General Reinforced concrete and prestressed concrete piles shall be designed in accordance with AS 3600, except as detailed in this Section. Grout piles shall be designed using the same principles.

The ultimate structural strength R_{us} shall be calculated in accordance with AS 3600.

5.3.2 Strength reduction factors—concrete piles The appropriate strength reduction factor chosen from AS 3600 shall be reduced to take account of the increased coefficient of variability in material properties in concrete placed in cast-in-place piles compared with concrete cast in forms assumed in AS 3600. In assessing the appropriate reduction factor, considerations such as the presence of permanent or temporary liners, the depth of the excavation, the method of concrete placement and the presence of water shall be taken into account. Depending on the combination of these factors, the strength reduction factors detailed in AS 3600 shall be multiplied by a further reduction factor of 1.00 to 0.75.

NOTE: The reduction factor of 1.0 would be appropriate for well controlled conditions with a high level of quality control. A value of 0.75 would be appropriate where conditions were not well controlled. Intermediate values may be selected based on relevant conditions and control procedures.

5.3.3 Strength reduction factors—grout piles In determining the design strength for piles constructed using grout, the strength reduction factors detailed in AS 3600 shall be multiplied by a further reduction factor as follows:

(a) Piles constructed in sandy soils and coarse grained rock . . . . 0.65–0.75.

(b) Piles constructed through or into clay soils and weak fine grained rock . . . . . . 0.5–0.65.

Selection of the reduction factors shall be based on local experience and the suitability of the grout mix for the soil conditions.

The characteristic strength of grout piles shall be determined from cube samples taken in accordance with AS 2701.2 and tested in accordance with AS 1012.

NOTE: It is not necessary to reduce the cube strength to an equivalent ‘cylinder strength’. The factor is taken into account in the strength reduction factors.

5.3.4 Reinforcement requirement Where reinforcement is required, the cross-sectional area of the longitudinal reinforcement in a pile shall—

(a) be not less than 0.005 A_g where a pile is fully embedded in the ground;

(b) be not less than 0.01 A_g for the portion of a pile projecting above the ground except that in a pile which has a larger area than that required for strength, a reduced value of A_{sc} may be used if $A_{sc} f_{sy}$ is greater than 0.15N*. At a depth of three piles diameters below the ground surface, the limit on longitudinal reinforcement may be reduced to 0.005 A_g, as in Item (a); and

(c) not exceed 0.04 A_g, unless it can be shown that the amount and disposition of the reinforcement will not prevent the proper placing and compaction of the concrete.

5.3.5 Partially reinforced pile Pile reinforcement may be curtailed one development length below a level where bending moments from all loads and eccentricities and tensile loads from uplift heave and others cease to be significant and provided that the design load in the unreinforced section does not exceed 0.5 $f'_c \phi_s A_g$.

NOTE: Attention should be paid to loads, moments and other actions induced by possible horizontal or vertical ground movements which would require longer or full length reinforcement.

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5.3.6 Unreinforced piles An unreinforced pile shall be permitted where the design action effect does not exceed the design strength calculated for plain concrete members in accordance with AS 3600.

5.3.7 Prestressed concrete pile A prestressed concrete pile shall be designed in accordance with AS 3600.

The minimum prestress in prestressed piles shall be as follows:

(a) Sufficient to resist the maximum calculated tensile driving stress as per Clause 7.3.3.1.

(b) Sufficient to resist lifting and handling stresses as per Clause 3.3.1.3.

5.3.8 Lateral restraint of longitudinal reinforcement and tendons Where piles project more than two pile diameters above final ground formation level, the minimum size of the tie or helix shall conform to AS 3600 requirements for columns for the portion of pile above the ground and for a depth of three diameters below the ground surface. Otherwise the details in Table 5.1 shall apply as a minimum.

TABLE 5.1

BAR SIZES FOR TIES AND HELICES

Pile size, mm	Longitudinal bar size	Minimum bar size of tie or helix, mm
Up to 500	Up to Y28	5
Up to 500	Y32 to Y36	6
501 to 700	all	6
701 and above	all	10

5.4 STEEL PILES

Steel sections shall be designed in accordance with AS 4100.

The structural design strength shall be calculated using the gross cross-sectional area less an allowance for loss of section due to corrosion, as detailed in Clause 6.3.

5.5 COMPOSITE STEEL CONCRETE PILES

Design of composite piles shall comply with AS 3600 for concrete sections and AS 4100 for steel sections. The design shall ensure adequate structural strength to transfer the design actions across the interface between materials.

NOTE: For example, in a partially concrete-filled steel tube pile, where the load must be transferred from the concrete section to the steel tube, the bond between the concrete and steel should take into account possible concrete shrinkage. Shear or bearing connectors may be required to transfer the load.

5.6 TIMBER PILES

5.6.1 General Timber piles shall be designed in accordance with AS 1720.1, except as detailed in this section.

The design structural strength shall be calculated using the expression below:

$$R_s^* = 1.68 \times \text{permissible stress} \times \text{strength reduction factor} \times \text{cross-sectional area}$$

The permissible stress shall be determined by the method detailed in AS 1720.1. Strength reduction factors are given in Table 5.2.

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NOTES:

1 The design structural strength calculated in the above expression is for long term loads. The short term strength may be obtained by multiplying by the appropriate factors in AS 1720.1—1988.

2 AS 1720.1—1988 is not written in limit state format. This Standard is presently under review, and the above calculation of R_s* will be reassessed when the limit state version of AS 1720.1 is completed.

TABLE 5.2

STRENGTH REDUCTION FACTORS FOR TIMBER PILES

Type of action effect	Strength reduction factor ϕ_s
(a) Compression	0.80
(b) Tension parallel to the grain	0.80
(c) Bending	0.80
(d) Compression, tension or bending in reduced sections, e.g. joints	0.70

NOTE: Consideration should be given to reducing the design strength to compensate for strength reduction resulting from possible biological attack and weathering.

5.6.2 Cross-sectional area The design strength shall be calculated taking account of potential variability in cross-section along the length of a pile.

If a timber pile is employed without adequate preservative treatment, the outer sapwood, which is non-durable on all timber species, shall not be considered for the purpose of measurement of cross-sectional area, load-bearing capacity or permanence in any other regard.

5.6.3 Timber pile splices In addition to the requirements of Clause 5.2.4, joints in timber piles shall conform to the following:

(a) Where a pile is made up of more than one section, the mechanical joint shall be designed for the design action effect at the joint, using a strength reduction factor given in Table 5.2.

(b) Where tube splices are used, account shall be taken in the design of the reduced tension and bending capacity of the joint.

NOTE: The strength reduction factor for joints takes into account the shaving factor, as defined in AS 1720.1, and the increased proportion of heartwood.

5.6.4 Connection details The connection of a pile to a structure shall be designed as follows:

(a) *Compression, lateral and bending loads* Where the pile terminates in a concrete pile cap, the depth and contact surface preparation of the pile projection into the cap shall be designed for compression, lateral and bending loads.

Where a pile terminates with other connection details, such as timber or steel headstocks, the connection shall be designed in accordance with the requirements of AS 1720.1.

(b) *Tension loads* Where a pile terminates in a concrete pile cap, the design tension load on a steel dowel passing through the pile head into the concrete shall be determined in accordance with Table 5.3. See also Figure 5.1.

The loads given in Table 5.3 apply to dowels with a minimum edge distance (l_1) to the end of the pile of 8 D_d. The pin shall extend a minimum distance d into the concrete cap.

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Other connection details into a concrete cap and connection details into timber or steel headstocks above ground level shall be designed in accordance with the requirements of AS 1720.1.

TABLE 5.3

TENSION CAPACITY OF STEEL DOWELS PASSING THROUGH THE PILE HEAD (Bearing parallel to timber grain)

Joint group*	Design tension load on dowel, kN				
	Dowel diameter (D_d), mm				
	16	20	24	30	36
J1	14	21.8	31.4	50	70
J2	11.6	18.2	26.2	40	58
J3	10.8	16.8	24.2	37.8	54
J4	8.4	13.2	19.2	29.8	44

* Joint group is given in AS 1720.1.

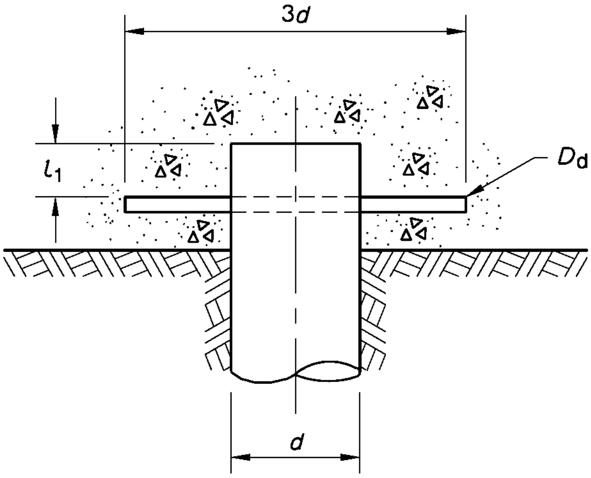

FIGURE 5.1 DETAILS OF DOWEL HEAD PINS TO TRANSMIT TENSION

(c) *Timber grading* A timber pile shall be inspected and graded for allowable defects in accordance with AS 2209, except for splits.

(d) *Barrel splits* Barrel splits shall be rated according to AS 2209, and such splits shall not exceed numerical rating No. 2 at the pile toe and No. 4 at the butt.

(e) *End splits* End splits at a pile toe shall not exceed numerical rating 2 and splits at the butt of a pile shall not exceed numerical rating 4.

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SECTION 6 DESIGN FOR DURABILITY

6.1 SCOPE The requirements of this Section apply to plain, reinforced and prestressed concrete, steel or timber piles with a design life of 40 to 60 years. Unless otherwise specified in this Section piles above ground shall be treated as columns in accordance with appropriate material design standards. Where piles are spliced, the relevant durability requirements shall apply to the splice material.

6.2 DESIGN FOR DURABILITY OF CONCRETE PILES

6.2.1 General Durability shall be allowed for in the design of concrete piles by assessing the exposure classification for a pile in accordance with Clause 6.2.3, and for that exposure classification, complying with the requirements for—

(a) minimum concrete strength and reinforcement cover in Clause 6.2.4(a);

(b) limitations on content of certain chemicals in Clause 6.2.4(b); and

(c) cover for concrete placement in Clause 6.2.4.(c).

6.2.2 Design life The provisions of this Code are intended for permanent structures, with a design life for both the concrete and the steel reinforcement of 40–60 years. Where more aggressive conditions occur or greater design life is required, consideration shall be given to a more conservative design requirement.

NOTE: Issues such as a maintenance-free period and client-acceptable levels of damage due to loss of durability may need to be taken into account.

6.2.3 Exposure classification for concrete piles The exposure classification of the surface of a concrete pile shall be determined from Table 6.1. For the range of chemical conditions in the soil surrounding the piles, the condition leading to the most severe aggressive conditions shall be allowed for, and allowance shall be made for likely changes in groundwater levels.

6.2.4 Durability requirements Durability of concrete piles shall be promoted by adherence to the following requirements:

(a) *Protective measures for durability* These measures shall be chosen—

  (i) by adoption of the minimum requirements of Table 6.2 in regard to concrete strength and cover for reinforcing steel and tendons;

  (ii) as otherwise assessed from proven experience; or

  (iii) by design life assessment of concrete durability, utilizing proven numerical procedures, (e.g. chloride diffusion analysis) supplemented by laboratory assessment under conditions which imitate the service life conditions, (e.g. chloride diffusion testing utilizing differential concentration cells).

  NOTE: Use of supplementary cementitious materials may increase durability and hence lead to lower cover requirements. Concrete strengths alone may not be the sole means of determining cover requirements.

(b) *Restrictions on chemical content in concrete piles* Restriction on chemical content shall apply as given in AS 3600.

(c) *Cover for concrete placement* For concrete placement, the following shall apply:

  (i) The cover and arrangement of steel shall be such that concrete can be properly placed and compacted.

  (ii) The cover shall be not less than either the maximum nominal aggregate size or as detailed in Table 6.2.

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TABLE 6.1
EXPOSURE CLASSIFICATION FOR CONCRETE PILES

Exposure conditions	Exposure classification
1 PILES IN WATER	
(a) Sea water—submerged	Moderate
(b) Sea water—tidal/splash zone	Severe
(c) Fresh water—treat as PILES IN SOIL (type A, see below)	—
(d) Running water (potential to create erosion)—treat as PILES IN SOIL (type A see below) below and move up to rating one level higher	—
2 PILES IN REFUSE FILL	
(a) Domestic waste	Severe
(b) Industrial waste	Very severe
3 PILES IN SOIL	

Sulfates Expressed as SO_3*		pH	Chlorides in water	Soil conditions†	Soil conditions‡
In soil %	In groundwater ppm		ppm	A	B
<0.2	<300	>6.5	<2 000	Non-aggressive	Non-aggressive
0.2–0.5	300–1 000	5–6	2 000–6 000	Mild	Non-aggressive
0.5–1.0	1 000–2 500	4.5–5	6 000–12 000	Moderate	Mild
1.0–2.0	2 500–5 000	4–4.5	12 000–30 000	Severe	Moderate
>2.0	>5 000	<4	>30 000	Very Severe	Severe

* Approximately 100 ppm SO_4 = 80 ppm SO_3.

† Soil conditions A—high permeability soils (e.g. sands and gravels) which are below groundwater.

‡ Soil conditions B—low permeability soils (e.g. silts and clays) or all soils above groundwater.

NOTES:

1 This is a simplistic and sometimes conservative approach to the definition of aggressivity. It is common to find more than one chemical in the service environment and the effect of these chemicals may be modified in the presence of others. For example, sulfate ions become aggressive at levels of 600 to 1000 ppm when combined with magnesium or ammonium ions. In the presence of chloride ions, however, attack by sulfate ions generally exhibits little disruptive expansion, with the exception of conditions of wetting and extreme drying where crystallization can cause surface fretting of concrete.

2 Corrosion damage by chlorides is only relevant to the steel reinforcement. If there is no reinforcement or the reinforcement is otherwise protected (e.g. by a coating or cathodic protection) the chloride content is not relevant.

3 Chemical concentrations relate only to the proportion of chemical present which is water soluble.

4 Acidic ground conditions can be caused by dissolved ‘aggressive’ carbon dioxide, pure and very soft waters, organic and mineral acids and bacterial activity. Care is required in assessment of pH under pile installation and lifetime conditions since pH can change over the lifetime of the pile. Testing for pH should be carried out either *in situ* or immediately after sampling as there is otherwise a risk of oxidation with time, leading to apparent acidity which does not correctly represent *in situ* conditions.

5 Contamination by the tipping of mineral and domestic wastes or by spillage from mining, processing or manufacturing industries presents special durability risks due to the presence of certain aggressive acids, salts and solvents which can either chemically attack concrete or lead to a corrosion risk. In the absence of site-specific chemical information, the exposure condition should be assessed as ‘severe’ for domestic refuse and ‘very severe’ for industrial/mining waste tips. Chemical analysis of the latter may, however, allow a lower risk classification.

6 For piles in disturbed soil consider the assumption of soil A conditions where accelerated corrosion is possible.

7 In severe and very severe conditions, where sulfate levels exceed 2000 parts per million in ground water or 1% in soil, reference should be made to AS 3735 and Supplement for advice on concrete design.

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TABLE 6.2

CONCRETE STRENGTH AND REINFORCEMENT COVER IN PILES

Exposure classification	Minimum concrete strength (f'_c) MPa	Minimum cover to reinforcement (mm)	
		Precast piles	Cast-in-place piles
Non-aggressive	25*	20	40
Mild	32	20	50
Moderate	40	25	55
Severe	50	40	70
Very severe	> 50, (preferably >60) plus an inert liner or coating	40	70

* For reinforced piles, use f'_c = 32 MPa minimum.

6.3 DESIGN FOR DURABILITY OF STEEL PILES

6.3.1 General Durability shall be allowed for in the design of steel piles by assessing the exposure classification for a pile in accordance with Clause 6.3.3 and for that exposure classification, complying with the requirements by one or a combination of—

(a) corrosion allowance for uncoated steel in Clause 6.3.4;

(b) coating systems in Clause 6.3.5; or

(c) cathodic protection systems in Clause 6.3.6.

6.3.2 Design life The design life of a pile shall be assessed and appropriate measures allowed for. Where no protective coating or cathodic protection is applied, allowance shall be made for loss of section during the design life. Where a pile coating is provided, consideration shall be given to the likely life of the coating and allowance made for loss of pile section thereafter, if appropriate.

6.3.3 Exposure classification for steel piles The exposure classification of the surface of a steel pile shall be determined from Table 6.3. For the range of chemical conditions of piles in soil, the condition leading to the most severe aggressive conditions shall be allowed for, and consideration shall be given to possible changes in groundwater levels.

6.3.4 Corrosion allowance for steel piles Where no protection systems are to be applied to steel piles, allowance shall be made for uniform corrosion and loss of section. Corrosion allowance shall be as tabulated in Table 6.4. In areas where site specific corrosion rates are known, those rates may be used. Corrosion on the internal faces of a fully-sealed closed-form pile may be assumed to be negligible.

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TABLE 6.3

EXPOSURE CLASSIFICATION FOR STEEL PILES

Exposure conditions				Exposure classification	
1 PILES IN WATER (a) Sea water—submerged (b) Sea water—tidal/splash zone (c) Fresh water, soft running water				 Severe Very Severe Moderate	
2 PILES IN REFUSE FILL (a) Domestic waste (b) Industrial waste				 (see Note 2) (see Note 2)	
3 PILES IN SOIL (see below)					
pH	Chlorides Cl		Resistivity	Soil conditions*	Soil conditions*
	In soil	In water ppm	ohm	A	B
>5	<0.5%	<1 000	>5 000	Non-aggressive	Non-aggressive
4–5	0.5–2%	1 000–10 000	2 000–5 000	Mild	Non-aggressive
3–4	2–5%	10 000–20 000	1 000–2 000	Moderate	Mild
<3	>5%	>20 000	<1 000	Severe	Moderate

* Soil conditions A—high permeability soils (e.g. sands and gravels) which are below groundwater.
Soil conditions B—low permeability soils (e.g. silts and clays) or all soils above groundwater.

NOTES:

1 Where high levels of sulfates exist, sulfate reducing bacteria may be present, leading to microbiologically induced corrosion. In such cases, classify as ‘mild’ for low permeability soils and ‘moderate’ for high permeability soils.

2 Contamination by the tipping of mineral and domestic waste or by spillage from mining, processing or manufacturing industries presents special durability risks due to the presence of certain aggressive acids, salts and solvents which can chemically attack steel. In the absence of site-specific chemical information, the exposure condition should be assessed as ‘severe’ for domestic refuse tips and ‘very severe’ for industrial/mining waste tips. Chemical analysis of the latter may, however, lead to lower risk classification.

3 For piles in disturbed soil consider the assumption of soil A conditions where accelerated corrosion is possible.

TABLE 6.4

CORROSION ALLOWANCES FOR STEEL PILES

Exposure classification	Uniform corrosion allowance (mm/year)
Non-aggressive	<0.01
Mild	0.01–0.02
Moderate	0.02–0.04
Severe	0.04–0.3
Very severe	0.1–0.5

NOTES:

1 The allowances in Table 6.4 may be reduced as appropriate where protection systems are to be used.

2 Where piles are electrically connected to a dissimilar metal, the resultant beneficial or adverse effect shall be taken into consideration.

3 To allow the use of cathodic protection in the future it is good practice to provide electrical continuity throughout the structure at the time of construction. In providing electrical continuity, consideration must be given to the likelihood of stray current corrosion, especially if the completed structure is of significant length adjacent to a cathodically protected system or within close proximity to direct current electrified traction systems.

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6.3.5 Coating protection systems Where coating protection systems are to be used they shall comply with the following:

(a) *Atmospheric coating protection of steel piles* Where coating is to be applied to steel piles above ground level and above the low watermark, it shall conform to the requirements of AS/NZS 2312.

(b) *Coating systems for submerged and below ground steel piles* Appropriate coating systems in order of increasing durability include the following:

(i) Zinc phosphate epoxy rich primer.

(ii) Epoxy mastic.

(iii) High build high solids epoxy

(iv) Ultra high build polyester.

(v) Polyethylene.

(vi) Polypropylene.

Consideration should be given to the type of coating, method of application, thickness of coating, surface preparation, expected life under service conditions and the possibility of damage of the coating during installation. If it is considered that the life of the coating will be less than the required design life for the pile, appropriate allowance shall be made for corrosion.

6.3.6 Cathodic protection Where cathodic protection is to be applied, it shall conform to the following:

(a) Underground steel coating systems shall comply with AS 2832.2.

(b) Submerged steel pile coating systems shall comply with AS 2832.3.

6.4 DESIGN FOR DURABILITY OF TIMBER PILES

6.4.1 Design life Consideration shall be given to the design life requirement and appropriate allowance made both in the selection of the timber and in the chemical treatment (where used).

6.4.2 Timber selection and treatment Timber piles shall be either treated or untreated having due regard to the soils and ground water into which they are driven (as defined in AS 1604) and to the type and permanency of the structure they support.

NOTES:

1 Where a timber pile is installed to a depth such that it is permanently below the ground watertable, chemical preservation may not be necessary as the timber will not be subject to conditions where degradation will occur. Any portion of the pile, however, which extends above this level will be subjected to environmental conditions including the potential for decay and termite attack.

2 The durability of an untreated hardwood timber pile in contact with the ground above the permanent water level can vary appreciably depending on the timber species used. AS 1604 categorizes timbers into groups of similar durability. For timbers in the most durable group, a design life of 25 years against decay and termites would be expected.

3 AS 1604 gives guidance to life expectancy for different species of timber in ground contact; local experience may also provide useful guidance.

6.4.3 Timber preservation Timber preservation for a pile shall be in accordance with AS 1604, Hazard level H5, for a pile not in contact with sea water and Hazard level H6 in the case of marine exposure where risk of marine borer attack exists.

6.4.4 Treatment after cut-off The head of a pile, which has been treated with a preservative, after cutting off to the required level, shall be coated with a suitable preservative and covered with a water-resistant membrane prior to casting the pile caps.

6.4.5 Marine piles Where possible, all attachments and cross-bracings shall be positioned above high tide mark.

NOTE: Where additional protection is needed for the piles physical barriers, such as plastic wraps and concrete jackets may be used.

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SECTION 7 MATERIALS AND CONSTRUCTION REQUIREMENTS

7.1 GENERAL

7.1.1 All materials Unless otherwise specified, all materials used in pile construction shall comply with the appropriate Australian Standard.

7.1.2 Concrete Materials for plain, reinforced and prestressed concrete shall comply with the requirements of AS 3600 and AS 1379.

7.1.3 Grout Materials for grout shall comply with AS 3600, AS 3972, ASTM C 566. Grout fluidifier shall comply with ASTM C 566, except that expansion shall not exceed 4%.

7.1.4 Steel Steel for piles and pile fitments shall comply with the requirements of AS 1163, AS 1302, AS 1450, AS 1554, AS 1579, AS 3678, AS 3679.1, AS 3679.2 and AS 4100.

7.1.5 Timber Timber for piles shall comply with the requirements of AS 1604, AS 1720.1 and AS 2209.

7.2 TOLERANCES AND DEFECTS

7.2.1 Positional tolerances Unless otherwise specified, the permissible positional deviation for a pile at cut-off level shall be as follows:

(a) For a pile installed from land, with a cut-off level no more than 2 m below piling platform level—

±75 mm in plan position and within 4% of the specified inclination for piles raked up to 1 in 5, and 7% for piles raked more than 1 in 5.

NOTE: Where a pile projects above the ground, a tighter inclination tolerance may be required.

(b) For a pile installed from land, with a cut-off level at or more than 2 m below piling platform level—

±(75 + 20 (h–2)) mm in plan position and within 4% of the specified inclination for piles raked up to 1 in 5, and 7% for piles raked more than 1 in 5, where h is the depth to cut-off in metres.

(c) For a pile installed from a floating plant—

±150 mm in plan position and within 4% of the specified inclination for piles raked up to 1 in 5, and 7% for piles raked more than 1 in 5.

(d) For a non-circular pile section, where orientation of the major axes is specified for strength or positional requirements—

rotational deviation from the specified alignment shall not exceed ±10°.

7.2.2 Cut-off levels Unless otherwise specified, a pile shall be trimmed to a cut-off level having a tolerance of ±25 mm from the design cut-off level. Special care shall be taken with a concrete pile to ensure that a full cross-sectional area of the pile is at cut-off level.

7.2.3 Trimming and capping When trimming a concrete pile, care shall be taken to prevent cracking or otherwise damaging the concrete below cut-off level or damaging the steel reinforcement. Any damaged concrete shall be removed and the damaged section adequately repaired. Weak concrete and laitance in cast-in-place piles shall be cut away to expose sound concrete.

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The head of a timber pile shall be cut off square to sound wood and the cut face shall be coated with a suitable preservative and covered with a water-resistant membrane prior to the casting of the pile cap.

All soil and other debris shall be removed from the top of a pile before constructing the pile cap.

7.2.4 Variation in pile depths If the installed pile depth is inconsistent with the design depth, a reassessment of founding depth shall be made. If necessary, additional geotechnical investigation shall be undertaken to determine the cause of the variation.

7.2.5 Defective piles Where a pile exceeds the above tolerances, is damaged or is otherwise defective, a reappraisal of the strength, serviceability and durability of the pile shall be performed.

Where the strength, serviceability or durability are found to be unsatisfactory, the pile shall be rectified, downgraded or replaced with one or more supplementary piles, as appropriate.

7.3 DISPLACEMENT PILES—PREFORMED

7.3.1 Dimensional tolerances Unless otherwise specified, concrete, steel or timber preformed pile sections shall be supplied to the following tolerances:

(a) *Length*—not less than the specified length.

(b) *Cross-sectional dimensions*—

   (i) concrete and steel piles +10, −5 mm of the specified dimensions; and

   (ii) timber piles—mean diameter not less than the specified diameter and the minimum diameter in substantially oval piles, not less than 80% of the specified diameter.

(c) *Straightness*—the tolerance on straightness of any portion and of the completed length of a pile shall be—

   (i) concrete and steel piles—1/250 of the length up to a maximum deviation of 50 mm;

   (ii) timber piles—a straight line joining the centres of the butt and the toe cross-section shall fall entirely within the pile for piles exceeding 13 m and within 50 mm of the centre-line of the section for shorter piles; and

   (iii) the maximum deviation of crooks or kinks in timber piles shall not exceed the values set down in AS 2209.

(d) *Joints*—where a pile is made up of more than one section, the maximum angular deviation at the joint shall not exceed 1 in 100, subject to the tolerance for the complete pile as stated in Items (c)(i) and (c)(ii).

   For timber piles using tube splices, as well as the above angular tolerance, each timber end within the splice shall not be out of square by more than 1 in 50. Tubes shall fit tightly onto the timber section.

(e) *Ends*—pile ends shall not be out of square by more than 1 in 50.

7.3.2 Handling and storage Piles shall be handled and stored so that they are not overstressed and in such a way as to prevent permanent distortion of any part.

Care shall be taken to avoid damage to the outer surfaces of piles in storage and during handling. If damage occurs which is detrimental to the design requirements, it shall be repaired prior to installation of the pile.

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7.3.3 Installation

7.3.3.1 *Driving stresses* The type and weight of hammer used for driving a pile shall be such that the driving energy produced is sufficient to install the pile without causing damage to the pile material. The driving energy shall be controlled as follows:

(a) The maximum calculated stress in concrete piles during driving shall not exceed $0.8 \times f'_{cm}$ in compression, and in tension the stresses shown in Table 7.1, where f'_{cm} is the compressive strength in MPa at the time of driving. The crack width shall not exceed the lesser of 0.3 mm or 0.01 times the concrete cover expressed in mm.

TABLE 7.1

MAXIMUM CALCULATED TENSILE DRIVING STRESS

Pile type	Tensile stress
Reinforced concrete piles:	
(a) Reinforcement quantity ≤ 2%	$0.8\sqrt{f'_{cm}}$
(b) Reinforcement quantity > 2%	$\sqrt{f'_{cm}}$
Prestressed concrete piles	Initial prestress

(b) The maximum calculated stress in steel piles during driving shall not exceed $0.9\ f_{sy}$.

(c) The maximum calculated compressive stress generated in timber piles during driving shall not exceed 1.5 times the stress grade for timbers, as defined in AS 1720.1. Where piles are jointed, the compressive stress at the joint section shall not exceed 0.9 times the stress grade for pole timbers, unless closefitting tube splices are used, where 1.5 × stress grade × shaving factor should be used based on the actual area within the splice sleeve.

Where stresses are actually measured during driving, the above values may be increased by up to 10%.

Reinforcement for precast concrete piles shall be determined in accordance with Clauses 3.3.1.3, 3.3.1.4 and 5.3.4.

7.3.3.2 *Founding criteria* Except where it is specified that a pile is to be founded at a specific level, site monitoring of geotechnical strength shall be assessed by measuring the net penetration of the pile per hammer blow.

In the latter case, the pile shall be driven until the net penetration and the temporary compression of the pile per hammer blow reach the values determined from dynamic analysis (wave equation analysis or dynamic piling formula) or the values obtained from piles which have been load-tested.

If specifying a required net penetration and temporary compression of pile per hammer blow, the effects of pile type, hammer type, mode of operation and ground condition shall be taken into account.

Where practicable, one or more piles shall be restruck after a specified period to assess the effects of time on pile capacity. If the blow count varies on redriving, the ultimate geotechnical strength shall be reassessed.

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7.3.3.3 *Pile heave* The order of driving piles shall be such as to minimize any lateral or vertical heave of a pile or pile group. Where heave of pile groups is likely to occur, pile top level readings with respect to a suitable datum shall be taken after driving, and again after neighbouring piles have been driven. For piles which have risen significantly, the ultimate geotechnical strength shall be re-assessed by re-driving or load tests or both. Where necessary, all heaved piles shall be re-driven to the original depth and resistance.

Where lateral displacement occurs during driving, the structural strength of the pile shall be assessed and appropriate corrective action taken.

7.4 DISPLACEMENT PILES—DRIVEN CAST-IN-PLACE

7.4.1 Dimensional accuracy Driven cast-in-place piles shall be constructed to the following limits of accuracy:

(a) *Cross-sectional dimensions*—not less than the specified dimensions at any point in the pile length.

(b) *Straightness*—tolerance on the straightness of the liner at the commencement of driving shall be 1/250 of the length of the liner. The tolerance on straightness of any portion, and of the completed length of a pile, shall be 1/100 of the length of the pile.

7.4.2 Liners A driven cast-in-place pile shall be installed using a temporary or permanent liner, as follows:

(a) The liner shall be of tubular section and of sufficient thickness, strength and rigidity to prevent distortion by ground pressure or by forces induced during the installation process.

(b) The liner shall be free from significant distortion or any internal projections which might prevent the proper formation of the pile.

(c) If specified, the toe of the liner shall be fitted with a pile shoe which shall be capable of withstanding the forces resulting from the installation process, and be designed to provide a watertight joint with the liner.

(d) The liner shall be installed in accordance with Clause 7.3.3.

(e) Unless otherwise specified, soil or water inside the liner shall be removed prior to concreting. If the water or soil cannot be removed, the liner shall be withdrawn and re-driven.

7.4.3 Construction During construction, the following shall be observed where appropriate:

(a) Reinforcing steel shall be inserted into the liner and fixed in its correct position, coaxial with the liner and with the specified cover.

(b) Concrete shall be placed to fill the entire volume of the pile without the formation of voids caused by entrapped air or lack of compaction. The volume of concrete shall be recorded.

(c) Concrete shall be placed in such a manner that the position of the reinforcement is maintained.

(d) The concrete shall be placed in sufficient quantity and with sufficient fluidity to ensure that, if the liner is withdrawn, the concrete is not lifted with the liner and there is no separation of the concrete and no inflow of soil or water.

(e) To avoid damage caused by ground heave and any other movement generated by driving, the sequence of pile installation shall be such that adjacent piles are not disturbed. Unless specified otherwise, no pile shall be installed within six pile diameters of adjacent piles until the concrete in these piles has taken an initial set.

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(f) The location of the load applied to the soil by construction equipment shall be far enough away from the pile being driven, and from recently constructed piles, to avoid displacement or squeezing of the column of concrete.

7.5 NON-DISPLACEMENT PILES

7.5.1 Dimensional accuracy Unless otherwise specified, non-displacement piles shall be constructed to the following limits of accuracy:

(a) *Cross-sectional dimensions*—not less than the specified dimensions at any point in the pile length.

NOTE: Where it is required that a socket be formed in material below the level to which a liner has been installed, it may be impractical to construct the shaft and the socket to the same dimensions because of the clearance required for excavation equipment. Allowance shall be made for this in the pile design.

(b) *Straightness*—the tolerance on straightness of any portion, and of the completed length of a pile, shall be 1/100 of the length of the pile.

7.5.2 Support systems To maintain stability of non-displacement piles in soil conditions which would otherwise collapse, one of the following support systems shall be used:

(a) *Liners* The liners shall comply with the requirements of Clause 7.4.2, as appropriate.

If it is intended to de-water liners to allow descent for inspection or hand excavation purposes, special attention shall be paid to local statutory regulations in this regard. No such inspection or hand excavation shall be allowed in piles having a liner diameter less than 0.75 m.

(b) *Timber shoring* Timber shoring shall be of sufficient thickness, strength and rigidity to prevent distortion by ground pressure or by forces induced during the installation process. The dimensions shall be such as to enable the full pile cross-section to be formed without restriction.

(c) *Drilling fluids* The constituents of drilling fluids, including drilling muds or water, and the methods of mixing and circulation, shall be such as to provide stability of the shaft until it is filled with concrete as follows:

(i) During construction of a pile, the level of the drilling fluid shall be maintained so that the internal fluid pressure always exceeds both the external ground water pressure and the active earth pressure throughout all potentially unstable strata.

The level of the drilling fluid shall be maintained at least 1.0 m above the natural watertable at all times during the construction process.

(ii) When using drilling mud as the drilling fluid, tests to determine density, viscosity and pH value shall be undertaken at the outset and until a consistent working pattern is established. Thereafter, tests for density and viscosity and pH shall be carried out regularly. If there is a change in the established working pattern, an additional test for pH shall also be carried out.

(iii) The density, viscosity and sand contents of the drilling fluid shall be such as not to impair the proper and complete placing of the concrete in the pile. A sample of fluid shall be taken from the base of the pile immediately prior to concreting to establish that these parameters are within acceptable limits.

(d) *Continuous flight auger*—Support by continuous flight auger shall comply with the requirements of Clause 7.5.6.

(e) Other effective support systems.

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7.5.3 Excavation of the pile shaft Precautions to be considered when excavating a pile shaft include the following:

(a) Excavation shall not take place close to other piles which have recently been cast, and which contain workable or unset concrete, if such excavation is likely to cause a flow of concrete or otherwise damage the pile. Unless specified otherwise, no pile shall be installed within three diameters of adjacent piles until the concrete or grout in these piles has taken its initial set.

(b) Where ground conditions are such that the top of the hole is unstable, then a liner, not less than 1 m long shall be placed at the top of the pile excavation to prevent collapse of the soil and extend 150 mm above the working level to restrain surface debris from accidentally entering the excavation during construction. Alternatively, a cast-in-place or precast concrete guide wall may be used to fulfil this purpose.

(c) All water which has entered or infiltrated into a pile excavation shall be removed, if practicable, immediately prior to concrete placement.

If the inflow of water is sufficiently large to prevent such removal, the pile excavation shall be filled with water to at least 1 m above the ground watertable and concrete placed by tremie methods in accordance with Clause 7.5.5(c).

7.5.4 Base and shaft preparation Where a pile is designed to carry part or all of its load by end-bearing or shaft friction or adhesion, it shall be founded in and underlaid by material such that the strength and serviceability design criteria for the pile are satisfied. Where soil or rock properties are inferior to the design assumptions, pile excavation dimensions shall be increased to satisfy the design requirements. Where specified the material below the base shall be proved for a predetermined depth.

The pile shaft and base shall be cleaned of loose material and debris to ensure that the design strength can be effectively mobilized.

Appropriate inspection methods shall ensure compliance with these requirements.

7.5.5 Construction During construction, the following shall be observed where appropriate:

(a) Reinforcing steel shall be fixed in its correct position and with the specified cover.

(b) Concrete shall be placed to fill the entire volume of the pile without the formation of voids caused by entrapped air, lack of compaction or segregation. The volume of concrete shall be recorded.

(c) Concrete shall be placed in such a manner that segregation of the concrete does not occur and that the position of the reinforcement is maintained.

(d) Piles constructed in a stable cohesive soil without the use of a temporary liner (other than that referred to in Clause 7.5.3(b)) or other form of support shall be concreted on the day the excavation is completed, unless otherwise specified. The concrete shall be placed so that it does not cause the excavation to collapse or cause spoil or other foreign matter to contaminate the concrete.

(e) The concrete shall be placed in sufficient quantity and with sufficient fluidity to ensure that, if the liner is withdrawn, the concrete is not lifted with the liner and there is no separation of the concrete and there is no inflow of soil or water.

(f) Concrete which is cast under water or under drilling fluid by tremie methods shall be placed without withdrawal of the tremie pipe from the concrete during the concrete discharge. Concrete placement shall continue until all laitance and contaminated concrete is above the pile cut-off level. Tremie concrete shall not be vibrated.

(g) Concrete placed by tremie shall have a cementitious content of not less than 400 kg/m^3.

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7.5.6 Continuous flight auger piles

7.5.6.1 *Installation* A pile shall be installed in accordance with the following:

(a) Unless specified otherwise, a pile shall be constructed up to ground surface level and at least 300 mm above design pile cut-off level.

(b) The sequence of pile installation shall be such that adjacent piles are not disturbed. Unless specified otherwise, no piles shall be installed within 3 diameters of adjacent piles until the concrete or grout in these piles has taken its initial set.

(c) The location of the load applied to the soil by construction equipment shall be far enough away from the pile being drilled, and from recently constructed piles, to avoid displacement or squeezing of the column of concrete or grout.

(d) The diameter of the auger shall not be less than the specified pile diameter.

(e) When the auger has reached the pile toe level, the pile hole shall be filled with the concrete or grout in an uninterrupted operation during extraction.

(f) During extraction, the auger shall be restrained against rotation in a direction counter to that used to advance the auger.

(g) The rate of injection and rate of auger withdrawal from the soil shall be co-ordinated so as to maintain at all times a positive pressure at the lower end of the auger flight. The pressure in the delivery line shall be measured by a pressure gauge or similar approved device, which shall be visible at all times to the operator responsible for controlling the withdrawal of the auger.

(h) The auger hoisting equipment shall be capable of withdrawing the auger smoothly and at a constant rate. Should material injection pressure fall during extraction, the auger shall be immediately re-drilled and the section of the pile where the injection pressure was reduced shall be reformed.

(i) The pumping equipment shall incorporate a measuring device so that the volume of concrete or grout used in the piles can be determined with an accuracy of 5%.

(j) The measured volume of concrete or grout placed in any pile shall be not less than 105% of the nominal volume of the pile.

(k) Unless otherwise specified reinforcing steel shall be inserted after construction of the concrete or grout column. In all soils, other than predominantly sandy ones, spacers shall be used as required to provide the necessary cover to reinforcement.

(l) After completion of each pile, precautions shall be taken to prevent objects falling into the column of liquid concrete or grout.

7.5.6.2 *Sampling and testing* During installation, samples shall be taken from the concrete or grout and tested to determine the characteristic strength.

For concrete piles, samples shall be in the form of cylinders taken and tested in accordance with AS 1012.

For grout piles, samples shall be in the form of cubes, taken in accordance with AS 2701.2 and tested in accordance with AS 1012.

7.6 RECORDS OF DATA

7.6.1 Driven displacement piles During the installation of driven displacement piles, the following information shall be recorded:

(a) Date of driving pile.

(b) Location and dimensions of the pile.

(c) Depth driven.

(d) Characteristics of driving equipment.

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(e) Final penetration for the last 10 blows and temporary compression for one of the blows, or as specified.

(f) Type and condition of the packing on the pile head, and of the dolly or follower if used.

(g) Sequence of driving in pile groups.

(h) Concrete mix properties, and slump and volume if applicable.

(i) Any apparent deviation from specified location and inclination.

(j) Any other relevant information.

A penetration record of blows per metre (or less) for the full length of the pile shall be taken for the first pile and other selected piles on the site.

7.6.2 Non-displacement piles During the installation of a non-displacement pile, the following information shall be recorded:

(a) Date and time of commencing and completing the pile excavation.

(b) Location and dimensions of the pile.

(c) Excavated depth.

(d) Installation method.

(e) Details of the soils and rocks penetrated.

(f) Concrete or grout mix properties, volume and slump, if applicable.

(g) Method, date and time of concreting or grouting, and whether any break occurred in the filling process.

(h) Water level, if any, at the time of concreting or grouting.

(i) Any other relevant information.

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SECTION 8 TESTING

8.1 SCOPE The requirements of this Section apply to—

(a) static and dynamic testing to assess the pile serviceability and, optionally, the ultimate geotechnical strength of the pile; and

(b) pile shaft integrity testing.

8.2 PILE LOAD TESTING

8.2.1 Test load types The appropriate pile load test shall be selected from one or more of the following tests—

(a) static testing—

(i) compression test;

(ii) tension test;

(iii) lateral load test; and

(b) dynamic testing—compression test.

NOTE: Other test methods may be developed in future and may be used at the discretion of the designer.

8.2.2 Information required When a pile load test is required, the type of testing and associated details shall be specified in a Schedule of Load Test Requirements (Figure 8.1), hereafter called the Schedule.

8.2.3 Acceptance of Piles The criteria for acceptance of test piles shall be as detailed in Clauses 8.3.5.6, 8.4.6 or 8.5.8, as appropriate. Piles not meeting this criteria shall be considered as defective piles in accordance with Clause 7.2.5. Piles similar to the test pile shall also be reassessed accordingly.

8.3 STATIC LOAD TESTING Static load testing shall be used to—

(a) evaluate pile performance at preliminary or later stages of work; or

(b) proof-test nominated piles as work proceeds.

8.3.1 Preparation for testing The pile head shall be prepared to allow application of the load coaxial with the pile axis for compression or tension tests and perpendicular to the pile axis for a lateral load test. The preparation shall enable the test load to be transmitted to the pile (e.g. through a steel bearing plate or other arrangement) with, at most, minor local damage or distortion to the pile head.

Any extension of the pile for the purpose of carrying out the test should be coaxial with the original pile and be of sufficient strength to sustain the proposed test loading.

8.3.2 Reaction system The test load shall be applied to the pile by jacking against a reaction system. The resultant force shall be coaxial with the pile for tension and compression tests and perpendicular to the pile for lateral load tests.

The reaction system may comprise ground or rock anchors, kentledge or reaction piles.

The reaction system shall be stable and shall provide safe access as required for testing personnel.

Minimum distances from the test pile centerline to anchorages, kentledge supports and reaction piles shall be as follows:

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(a) *Anchorages* Where ground anchors are used to provide a test reaction—

(i) no part of the bonded section of the anchor shall be closer to the centre-line of the pile than three times the shaft diameter of the pile; and

(ii) where the test pile has an enlarged base, no part of the bonded section of the anchor shall be closer to the pile base centre-line than a distance equal to the base diameter.

NOTE: If two anchors are used, one at each end of the loading beam, precautions should be taken to prevent any tendency for sideways buckling of the beam.

(b) *Kentledge* Where kentledge is used to provide a test reaction—

(i) no part of the kentledge support system shall be closer to the pile centre-line than a distance of 2.5 times the shaft diameter of the pile; and

(ii) the weight of the kentledge shall be transferred to the ground in a manner such that—

(A) the load is transferred symmetrically around the pile head;

(B) the stability of the kentledge is maintained at all times; and

(C) any tendency of the kentledge to tilt or sway is minimized.

Loads shall not be applied by supporting the kentledge directly on the pile or pile cap.

(c) *Reaction piles* Where reaction piles are used to provide a test reaction, the centre-to-centre spacing between vertical reaction piles and the test pile shall be not less than the greater of—

(i) five times the test pile diameter; and

(ii) 2.5 m.

NOTES:

1 Non-displacement piles should be used to provide reaction for test loading in preference to displacement piles. Installation of displacement reaction piles should precede test pile installation, wherever practicable. Non-displacement piles may be installed before or after the pile to be tested.

2 Where a working pile is used as a reaction pile which is loaded in tension, displacement of the pile should be monitored throughout the test, and appropriate measures (e.g. redriving the pile) should be taken to ensure that any permanent displacement of the reaction pile does not affect its in-service performance.

Departures from these minimum distances shall be permitted provided an assessment of the interaction between the test pile and the reaction system is made. Details of any such interaction assessment shall be included in the pile test report.

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SCHEDULE OF LOAD TEST REQUIREMENTS

This Schedule shall be completed where applicable.

1. **Pile type and size** . . . .

2. **Method of installation** . . . .

3. **Type of test** . . . .

   (a) Compression test.

   (b) Tension (uplift) test.
   (Detail in Item 6 below if requirements differ.)

   (c) Lateral load test.
   (Detail in Item 7 below if requirements differ.)

   (d) Other (e.g. dynamic testing), as detailed in Item 8 below.

4. **Maximum load and pile movement**

   (a) The loading system shall have a capacity of at least . . . . kN.

   (b) The overall loading and measuring system shall be capable of accommodating a pile movement (measured at the pile head or cap) of at least . . . . mm.

5. **Commencement of loading** The minimum period between installation of the test pile and commencement of the pile test shall be . . . . . days.

6. **Tension (uplift) load test program**

   . . . .

   . . . .

7. **Lateral load test program**

   . . . .

   . . . .

8. **Requirements different from or additional to those specified in AS 2159**

   . . . .

   . . . .

9. **Acceptance criteria (if different from Clauses 8.3.5.6, 8.4.6 or 8.5.8, as appropriate)**

   . . . .

   . . . .

FIGURE 8.1 SCHEDULE OF REQUIREMENTS

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8.3.3 Equipment for loading and test measurement

8.3.3.1 *General* Equipment for applying the test load shall—

(a) have a load capacity not less than the maximum required load specified in the Schedule;

(b) be capable of accommodating the maximum required pile movement specified in the Schedule plus the displacement of the reaction system that occurs during loading;

(c) be capable of applying a controlled increase or decrease in load; and

(d) be capable (in the case of a sustained load test) of maintaining a constant load for the specified period.

8.3.3.2 *Measurement of load* Load cells shall be used to measure load and shall maintain stable calibration during testing.

The load measuring device shall—

(a) be accurate to within 2% of the indicated load and of stable construction; and

(b) have a calibration certificate issued within the preceding six months.

NOTE: When using a Bourdon gauge for load measurement in cold conditions, problems with freezing or sticking have been noted.

8.3.3.3 *Measurement of pile displacement* The following shall be observed:

(a) *General* The displacement of the pile shall be monitored by precise levelling or by a system of dial gauges, or electrical transducers in conjunction with a reference frame in order to provide an accurate measure of the absolute displacement and any rotation or tilt of the pile head.

The displacement measuring devices shall—

(i) be accurate to within the lesser of 0.1% of the pile shaft diameter, and 0.5 mm;

(ii) have sufficient travel to accommodate the maximum pile head movement or the required differential displacement between the test pile and a reference frame; and

(iii) be shielded from direct sunlight or other environmental influences.

Where dial gauges or electrical transducers are used, a minimum of four such gauges or transducers, spaced equally around the pile and equidistant from the axis of loading, shall be utilized.

NOTE: Approximate pile head displacements may additionally be determined using two parallel reference wires, one on either side of the pile, and held under constant tension. The wires should be positioned against scales fixed to the pile head. Supports for the reference wires should conform to the requirements for the reference frame, given in Item (b) below.

(b) *Reference frame* Pile displacements may be measured relative to a reference frame that is independent of the reaction system and the test pile.

The reference frame shall be—

(i) shielded from the direct sunlight or other environmental influences;

(ii) sufficiently robust to minimize distortion due to temperature differences;

(iii) mounted preferably to a minimum of five pile shaft diameters from the pile and any part of the reaction system, to minimize ground movement effects; and

(iv) checked for movement by independent levelling during the test with such movements applied as a correction to the apparent pile head movements.

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(c) *Level datum* A level datum shall be established on a permanent object or other well-founded structure or deep datum point. Movements of the pile head or the reference frame shall be related to this datum using a precise level located approximately equidistant from the datum and the test.

A secondary measurement system shall be used throughout the test to check that there has been no displacement in the reference frame.

8.3.4 Test procedure The static load test detailed in this Section is the incremental sustained load test (ISL) as specified in Clause 8.3.5. The primary objectives of the test are—

(a) to assess the performance of the pile footing under the design action effect for serviceability; and

(b) to assess the ultimate geotechnical strength of the pile footing.

NOTE: Consideration may be given to performing a CRP test or QML test both of which are suitable for assessing the ultimate geotechnical strength.

The standard load schedule for compression tests is detailed in Table 8.1.

TABLE 8.1

INCREMENTAL LOAD

Load **% of design action effect (*S****)**	**Minimum load duration**
15	15 min
30	15 min
45	15 min
60	15 min
design serviceability load (see NOTE)	6 h
37	5 min
0	5 min
37	15 min
75	15 min
90	15 min
105	15 min
120	15 min
135	15 min
150	1 h
105	5 min
75	5 min
37	5 min
0	5 min

NOTE: The design serviceability load is typically 75% of the design action effect, *S**

Variations to the standard load test procedures may be specified in the Schedule in Figure 8.1.

NOTE: Consideration may be given to performing a constant rate of penetration test (CRP), as an alternative to the quick maintained load test.

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Load schedules for tension and lateral load tests shall be specified in the Schedule of load test requirements.

Where a pile must sustain significant cycle or surge loading, the load test shall include an assessment of the additional displacements.

8.3.5 Incremental sustained load test (ISL)

8.3.5.1 *General* Where an incremental sustained load test is required, loading and unloading shall be carried out—

(a) in stages as shown on Table 8.1; or

(b) as otherwise specified in the Schedule.

8.3.5.2 *Maximum test load* The maximum test load applied to the pile for compression load test shall be 1.5 S^* and for tension or lateral load tests shall be 1.2 S^*.

Where maximum test loads applied for tension or lateral load tests are higher than specified by this Standard, consideration shall be given to the potential effects of permanent pile deflection on pile performance.

8.3.5.3 *Load application* Following application of each increment, the load shall be sustained at a constant magnitude until the rate of movement of the pile head is less than 0.5 mm per 15 min, but in no case less than the minimum specified holding time.

8.3.5.4 *Recording during the loading stages* Simultaneous records of load, pile head movement and time shall be taken—

(a) immediately upon reaching the load;

(b) at intervals of 1, 2 and 5 min and, where appropriate, 10 and 15 min after reaching load;

(c) where appropriate, at 15 min intervals thereafter up to 1 h;

(d) where appropriate, at 30 min intervals after 1 h; and

(e) immediately prior to each load application.

Check measurements of the reference frame shall be taken at the end of each loading increment.

The progress of the pile test, as the variation of the pile head load and pile head movement with time, shall be recorded graphically as an aid to monitoring pile and pile test performance. Such graphs may be used to detect instability in the pile or reaction system and to modify or abort the test.

8.3.5.5 *Recording during unloading stages* During unloading stages, the load, settlement, and time shall be recorded immediately on reaching the load decrement and immediately prior to the removal of the next load decrement.

8.3.5.6 *Acceptance criteria* The pile performance under compressive test loading shall be deemed to comply with this Standard provided that all the criteria in Table 8.2 are not exceeded.

Any criteria specified in the schedule shall take precedence over the values in Table 8.2.

NOTES:

1 The acceptance criteria for a pile in service will usually depend on structural consideration and the default values in Table 8.2 should be reviewed in relation to the structural requirements.

2 Long piles may be subject to an elastic compression which may approach the values in Table 8.2, and the limit value shown for serviceability load may need to be increased.

For tension and lateral load tests, the acceptance criteria shall be specified prior to the test.

If the acceptance criteria are not met, then a reassessment of the design geotechnical strength shall be done.

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TABLE 8.2

COMPRESSION LOAD TEST ACCEPTANCE CRITERIA

Load	Maximum deflection mm
Serviceability load	15*
0 (after removing serviceability load)	7*
1.5 × design action effect (*S**)	50
0 (after removing 1.5 × design action effect)	30

* Movement to include no more than 3 mm creep over 5 h (after load has been in place for 15 min).

8.3.6 Supervision and recording of results The pile test shall be carried out under the direction of a suitable person experienced in the supervision of static pile load tests.

NOTE: It is the intent of this Standard that the pile test be carried out under the directions of a professional engineer.

The setting up of pile testing equipment shall be carried out under the supervision of experienced personnel and the equipment shall be checked to ensure that the setting up is satisfactory before the commencement of load application.

The test shall be attended by a person who is fully conversant with the test requirements and capable of taking and recording accurate readings.

8.3.7 Report A report shall be prepared containing all relevant information including the following:

(a) Details of any available site investigation data at or near the test location.

(b) A description of the test pile.

(c) A description of the forming or driving of the pile.

(d) The results of any testing of pile materials.

(e) Details of the test reaction system including any technical assessment made of the effects of the reaction system on potential pile performance.

(f) Details of the measurement system and reference frame.

(g) Details of the load test program.

(h) A record of the time, test load, pile head movement relationship throughout the test. The record shall clearly indicate whether the results are uncorrected readings or readings that have been corrected for calibration, movement of datum points, or other influences.

(i) Where specified, an interpretation of the results of the test.

(j) Reference to this Australian Standard, i.e. AS 2159.

8.4 DYNAMIC PILE TESTING

8.4.1 General Dynamic pile testing, which mobilizes all or part of the available pile static capacity, shall be used when specified or required for any of the following:

(a) To proof-test nominated piles as work proceeds (as a supplement to static pile load testing).

(b) To predict the ultimate geotechnical strength at preliminary or later stage of work.

(c) To provide an indication of resistance distribution.

(d) To monitor pile stresses during installation (and thus avoid pile damage).

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(e) To assess hammer energies to confirm input for driving formula.

(f) To estimate and confirm parameters used in wave equation data.

(g) To check assumptions made concerning pile driveability.

(h) To assess pile integrity.

8.4.2 Pile preparation Pile preparation for testing shall involve all practical steps to ensure that the hammer and pile are aligned to prevent bending of the pile during the test blows, and that the hammer strikes a flush sound surface perpendicular to the pile axis.

NOTES:

1 Transducers should be attached to the pile shaft diameter a minimum of 1.5 diameters below the pile head. The sides of the pile should be smooth to prevent inducing bending in transducers as they are attached to the pile.

2 Cast-in-place piles should be provided with sufficient transverse reinforcement or a steel containment ring to withstand bursting stresses at the pile head caused by the dynamic impact. Care should also be taken to provide a flush surface perpendicular to the pile axis.

8.4.3 Hammer energy The dynamic pile test shall be carried out using a hammer energy sufficient to mobilize the pile strength requirements as specified in the Schedule. Where the purpose of the test is to assess the ultimate geotechnical strength of the footing, the energy of the blow shall be sufficient to mobilize the static resistance equivalent to at least 150% of the design action effect (S^*).

NOTE: Dynamic testing may be carried out during pile installation (driving test) or at any time thereafter (restrike test). The geotechnical strength of the pile may be predicted by dynamic testing either during installation or preferably restrike. However, the ultimate geotechnical strength may only be assessed if sufficient pile movement is induced by the impact loading.

8.4.4 Instrumentation Minimum instrumentation for a dynamic pile test shall consist of pairs of transducers, diametrically opposed around the pile, to measure transient strain (or force) and acceleration (or velocity) together with instrumentation to measure and record data from the transducers. The strain or force transducers shall be calibrated within the previous six months. The calibration of any transducers used in situations where overstressing is suspected shall be checked before further use.

8.4.5 Test procedure The test procedure shall follow that specified in the Schedule, bearing in mind the primary objectives of the test, namely—

(a) to assess the performance of the pile footing under the design serviceability load; and

(b) to demonstrate a reserve of strength above the design action effect (S^*).

The dynamic pile test shall be carried out by impact from an appropriate pile driving hammer or drop weight, of sufficient energy to satisfy the specifications in the Schedule. Care shall be taken to ensure alignment of the hammer and pile to minimize bending of the pile during the test.

Dynamic test procedures may be specified to assess the pile performance at the design serviceability load and to confirm compliance with the design geotechnical strength. Where the purpose of the test is to verify design action effect, the energy of the blow shall be sufficient to mobilize at least 150% of the design action effect.

The load test procedures shall be specified in the Schedule as per Figure 8.1.

These procedures may include a requirement for rigorous analysis using full wave signal matching of the recorded data obtained from the instrumentation transducers.

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8.4.6 Acceptance criteria The pile when tested in accordance with this Section shall comply with the following:

(a) The pile head movement does not exceed—

(i) 12 mm at design serviceability load; and

(ii) 35 mm when the load is 1.5 × design action effect.

(b) Alternative criteria stipulated in the Schedule.

Any criteria specified in the Schedule shall take precedence over the above values.

8.4.7 Supervision and recording of results Pile tests shall be carried out under the direction of a suitable person experienced in the supervision of dynamic pile load tests.

NOTE: It is the intent of this Standard that the pile test be carried out under the direction of a professional engineer.

The setting up of pile testing equipment shall be carried out under the supervision of experienced personnel and the equipment shall be checked to ensure that the setting up is satisfactory before the commencement of the test.

The test shall be attended by a person who is fully conversant with the test requirements and capable of taking and recording accurate readings.

8.4.8 Report A report shall be prepared containing all relevant information including the following:

(a) Pile details, including pile number, type, size, length, penetration and location of test gauges.

(b) Installation details, including date and time, driving system, together with each component above the pile head (cushions, helmet, hammer, follower and similar), hammer stroke or drop, pile set and temporary compression.

(c) Test details as for Item (b), if the test was performed subsequent to installation or if details for the test differed from the normal installation procedure.

(d) For each pile test, the maximum compressive and tensile stresses in the pile, the maximum pile head velocity, pile head displacement and the energy transfer. These should be either for a representative blow or be averaged over a number of blows.

(e) An assessment of pile integrity (or damage) at the time of testing.

(f) The method of capacity prediction and the maximum mobilized resistance by this method.

(g) Any assumptions critical to the capacity prediction (e.g. damping factor). Justification for such assumptions should be provided.

(h) Reference to this Australian Standard, i.e. AS 2159.

In addition, where rigorous analyses are performed, the full results of such analyses should be made available, and the following additional information provided:

(i) Predicted pile head movement at the maximum serviceability limit state, and at the maximum mobilized resistance.

(ii) Shaft and end bearing components of the maximum mobilized resistance.

8.5 INTEGRITY TESTING

8.5.1 General Pile integrity testing shall be used when specified or required as a method of proof-testing a pile as work proceeds with the aim of indirectly assessing one or more of the following:

(a) The structural integrity of the pile.

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(b) The relative shape of the pile shaft and an estimate of the physical dimensions of the pile or both.

(c) The continuity of the pile.

Pile integrity testing, when specified, shall be performed on a sufficient number of piles.

8.5.2 Preparation for testing Where the method of testing requires the positioning of sensing equipment on the pile head (sonic and vibration methods), the head shall be clean, free from water, laitance, loose concrete, overspilled concrete and blinding concrete, and readily accessible for the purpose of testing.

Where the method of testing requires the pile length to be logged, tubes shall be cast into the pile to allow the passage of a sonic pulse from a transmitter to a receiver through the material of the pile.

8.5.3 Time of testing In the case of cast-in-place concrete or grout piles, integrity tests shall not be performed until one week or more has elapsed since casting of the pile or until concrete or grout strength has achieved 25 MPa.

8.5.4 Test procedure Where integrity testing is required, the test to be adopted shall be one of the following:

(a) Sonic impact test (SIT).

(b) Sonic vibration test (SVT).

(c) Sonic logging test (SLT).

(d) Alternative test as specified.

8.5.5 Sonic impact test (SIT)

8.5.5.1 *General* Where a sonic integrity test is required, testing shall be carried out as specified.

8.5.5.2 *Application of impact* The pile head shall be impacted by a small hammer or similar in such a manner as to generate a sharp stress-wave, free from distortion, and of as short a wavelength as possible.

8.5.6 Sonic vibration test

8.5.6.1 *General* Where a sonic vibration test is required, testing shall be carried out as specified.

8.5.6.2 *Application of impulse* The required impulse shall be generated either—

(a) by impacting by a small hammer or similar in such a manner as to generate a sharp stress-wave, free from distortion, and of as short a wavelength as possible; or

(b) by attaching an electrodynamic vibrator to the pile head and generating sinusoidal stress waves of constant amplitude.

8.5.7 Sonic logging test (SLT)

8.5.7.1 *General* Where a sonic logging test is required, testing shall be carried out as specified below.

8.5.7.2 *Application of the sonic pulse* Sonic pulses shall be emitted from a transmitter to a receiver which may be moved through tubes over the length of the pile, either in unison or singly to determine a sonic profile.

8.5.8 Acceptance criteria The pile test shall be deemed to comply with this Standard provided that the results do not indicate any lack of structural integrity, change in physical dimensions, discontinuity or inconsistency in materials used for the pile that are likely to affect the ability of the pile to perform its intended function.

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Where anomalous results are recorded, consideration shall be given to the need for further alternative testing.

8.5.9 Supervision and recording of results Pile tests shall be carried out under the direction of a suitable person experienced in the supervision of pile integrity tests.

NOTE: It is the intent of this Standard that the pile test be carried out under the directions of a professional engineer.

The setting up of pile testing equipment shall be carried out under the supervision of experienced personnel. The equipment shall be checked to ensure that the setting up is satisfactory before commencement of the test.

The test shall be attended by a person who is fully conversant with the test requirements and capable of taking and recording accurate readings.

8.5.10 Report The report shall summarize the results of the pile integrity tests, and shall identify piles in which abnormal sonic reflectors or transmitters have been identified. The significance of these reflectors or transmitters shall be assessed with respect to the ability of the piles tested to perform their intended function.

Full details of the ground conditions, nominal pile dimensions and construction methods shall be made available to the testing professional engineer when required in order to facilitate interpretation of the tests.

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