BUILDING
PERFORMANCE

B1

B1 Structure

Verification Method B1/VM2

Geotechnical design of foundations

SECOND EDITION | EFFECTIVE 28 JULY 2025

MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
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Te Kāwanatanga o Aotearoa
New Zealand Government

Preface

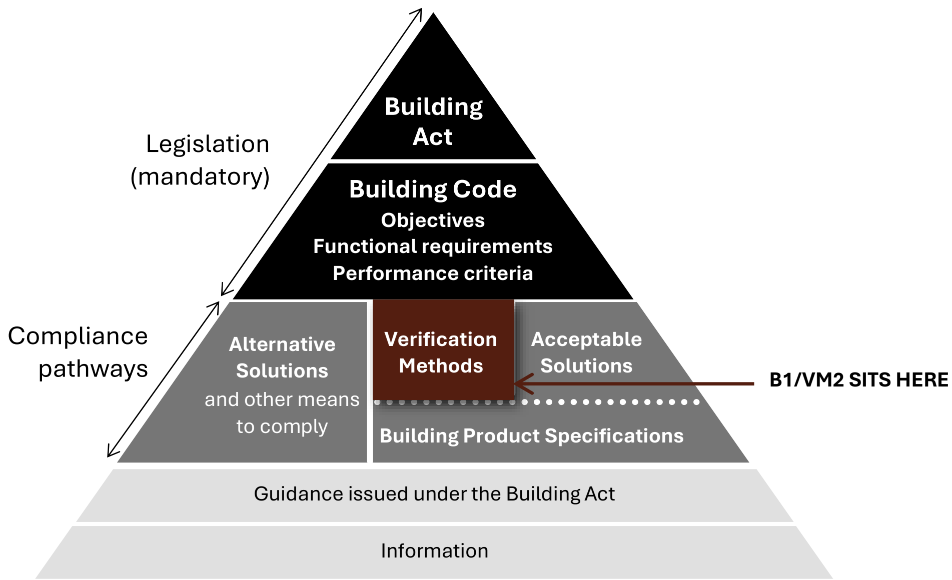
Document status

This document (B1/VM2) is a verification method issued under section 22 (1) of the Building Act 2004 and is effective on 28 July 2025. It does not apply to building consent applications submitted before 28 July 2025. The previous Verification Method B1/VM4 First Edition, as amended, can be used to show compliance until 31 July 2026 and can be used for building consent applications submitted before 1 August 2026.

Building Code regulatory system

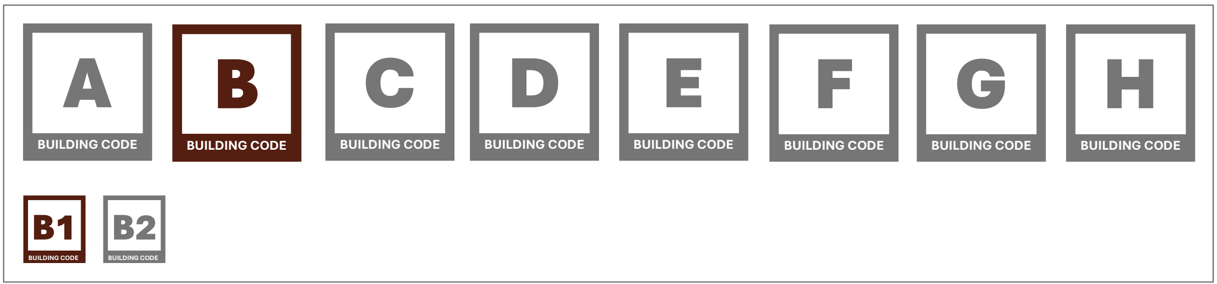
Each verification method outlines the provisions of the Building Code that it relates to. Complying with an acceptable solution or verification method are ways of complying with that part of the Building Code. Other options for establishing compliance are listed in [section 19 of the Building Act](#).

Schematic of the Building Code system



A building design must take into account all parts of the Building Code. The Building Code is located in Schedule 1 of the Building Regulations 1992 and available online at www.legislation.govt.nz.

The part of the Building Code that this verification method relates to is clause B1 Structure. Information on the scope of this document is provided in Part 1. General.



Further information about the Building Code, including objectives, functional requirements, performance criteria, acceptable solutions, and verification methods, is available at www.building.govt.nz.

Main changes in this version

This verification method is the second edition of B1/VM2. The main changes from the previous version are:

- The document has a new title. The previous version of this document was published as B1/VM4 Foundations. There were no current versions of B1/VM2 or B1/VM3.
- The document has been published in a standalone format and the layout has been revised to improve clarity. This includes using a common structure for headings and text throughout the verification method.
- Minor amendments have been made to correct typos, grammar, cross-references, punctuation, wording, and formatting of the document. This includes changes to headings, paragraphs, tables and figures, table and figure notes, and definitions. These amendments do not affect the level of performance required in the document but may assist in the interpretation of the requirements.
- Additional information on the document and its scope is provided in Part 1. General. Other general information in the verification method has been relocated to Section 1.2.
- Requirements for different types of foundations are now found in Part 2. Shallow foundations and Part 3. Pile foundations.
- The verification method now refers to the Building Product Specifications for timber piles in Paragraph 3.1.4.5.
- References have been revised to reflect the documents cited in this verification method in Appendix A.
- Definitions have been revised to reflect the terms used in this acceptable solution in Appendix B.
- An informative example for a retaining wall foundation has been removed from the document.

People using this document should check for amendments on a regular basis. The Ministry of Business, Innovation and Employment may amend any part of any acceptable solution or verification method at any time. Up-to-date versions of acceptable solutions or verification methods are available from www.building.govt.nz.

Features of this document

- For the purposes of Building Code compliance, the standards and documents referenced in this verification method must be the editions, along with their specific amendments listed in Appendix A.
- Words in *italic* are defined at the end of this document in Appendix B.
- Hyperlinks are provided to cross-references within this document and to external websites and appear with a blue underline.
- Appendix C. Informative appendices is for information only and does not form part of this verification method. Figures are informative only and the wording of the paragraphs takes precedence. Text boxes headed 'COMMENT' occur throughout this document and are for guidance purposes only.
- A consistent number system has been used throughout this document. The first number indicates the Part of the document, the second indicates the Section in the Part, the third is the Subsection, and the fourth is the Paragraph. This structure is illustrated as follows:

2	Part
2.5	Section
2.5.3	Subsection
2.5.3.1	Paragraph
2.5.3.1(a)	Paragraph (as a portion of the relevant paragraph)
2.5.3.1(a)(i)	Paragraph (as a portion of the relevant paragraph)

Contents

Part 1. General

1.1 Introduction

1.1.1 Scope of this document

1.1.1.1 The scope of this verification method covers geotechnical design of foundations. It can be used for the:

a) the ultimate limit state design of foundations, including those of earth retaining structures; and

b) the ultimate bearing and lateral sliding strengths.

1.1.2 Items outside the scope of this document

1.1.2.1 This document does not describe a means of determining the value of the soil parameters used in the verification method (such as c', ϕ', and s_u). The derivation of these parameters, which must be based on the most adverse moisture and groundwater conditions likely to occur, is outside of the scope of this verification method.

> COMMENT: Appendix C.1Site investigation contains information on the types of investigations that may need to be conducted to determine the soil parameters.

1.1.2.2 Serviceability limit state deformations are not covered in this document. The determination of such deformations and their acceptability to the design in question needs to be considered but is outside the scope of this document.

> COMMENT: Appendix C.2 Foundation settlement contains information that may be of assistance in designing for serviceability limit state deformations.

1.1.2.3 This document assumes general ground or slope stability and provides methods only for ensuring against local failure of the foundation. Overall ground stability needs to be verified before this document can be applied; this is outside the scope of this verification method.

1.1.2.4 This document must not be used to design foundations on loose sands, saturated dense sands or on cohesive soils having a sensitivity greater than 4.

> COMMENT: Saturated sands may be subject to liquefaction during earthquake loading and sensitive clays exhibit a rapid decrease in undrained shear strength once the peak strength has been mobilised. The design of foundations on these materials needs special considerations which are not covered in this verification method.

1.1.2.5 This document shall not be used for geotechnical design of foundations subject to continuous vibration.

> COMMENT: Although this document covers the geotechnical design of foundations subject to vibration from earthquake loading, it does not cover those applications where foundations are subject to continuous vibration such as from the operation of certain machinery.

1.1.3 Compliance pathway

1.1.3.1 This verification method is one option that provides a means of establishing compliance with some of the functional requirements and performance criteria in Building Code clause B1 Structure. It can be used to demonstrate compliance with clauses B1.2, B1.3.1, B1.3.2, B1.3.3, B1.3.4, B1.3.6, and B1.3.7 as relevant.

1.1.3.2 If this verification method cannot be followed in full, use an alternative means to demonstrate compliance.

1.2 Using this verification method

1.2.1 Design loads and geotechnical engineering design methods

1.2.1.1 Foundations in this verification method must be designed for the load combinations given in AS/NZS 1170.0, as amended by Verification Method B1/VM1. *Strength reduction factors* given in this document must be used to determine the design strength of the foundation. The design loadings must not cause the foundation's design strength to be exceeded.

1.2.1.2 The design procedures of this document must be performed by a person who, on the basis of experience or qualifications, is competent to apply them.

1.2.1.3 The *building*'s foundation elements or the elements of earth retaining structures shall be designed in accordance with the appropriate material standards, as given in Verification Method B1/VM1.

1.2.1.4 Foundations may be shallow or deep. A shallow foundation is one in which the depth from the ground surface to the underside of the foundation is less than five times the width of the foundation. All other foundations are considered to be deep.

1.2.1.5 In assigning values for soil parameters, the worst groundwater condition shall be considered.

> COMMENT: For cohesive soils the fully saturated condition will generally give the lowest strength and stiffness.

1.2.1.6 Foundation strength for cohesive soil depends on loading duration and whether consolidation can occur. For this reason, the distinction is made between short term (such as the initial load application, earthquake actions or wind gusts) and long term loading (such as permanent loads such as foundation dead load). For the short term case no consolidation occurs and the calculations shall be in terms of undrained shear strength (that is, the shear strength of the soil s_u) and total stress. For long term loading, full consolidation occurs and the calculations shall be in terms of drained shear strength and effective stress (the soil parameters being cohesion, c', and the angle of shearing resistance ϕ').

1.2.1.7 For cohesionless soils consolidation occurs very quickly so drained strength shall be used in all cases.

1.2.1.8 Design assumptions and soil parameters shall be verified during *construction*. The designer shall nominate what supervision, including verification of soil parameters, will be undertaken during the *construction* period.

1.2.2 Building Product Specifications

1.2.2.1 This verification method refers to the Building Product Specifications for *building* product standards and specifications in relation to their manufacture, fabrication, testing, quality control, physical properties, performance, installation, and/or maintenance

1.2.2.2 The Building Product Specifications cannot be used in isolation to demonstrate compliance with any requirements of the Building Code. To comply with B1/VM2, *building* products conforming to the Building Product Specifications must be used with the scope, limitations, and other applicable requirements set out in this verification method.

Part 2. Shallow foundations

2.1 Demonstrating compliance

2.1.1 Overview

2.1.1.1 Verification of the design is achieved by demonstrating that the design bearing pressure (q_d) does not exceed the design bearing strength (q_{dbs}).

2.1.1.2 The design bearing pressure (q_d) shall be determined by dividing the design vertical forces (V) (derived from combinations of factored vertical loads) by the effective area of the foundation (A'). Refer to Subsection 2.2.1.3 for the calculation of the effective area.

2.1.1.3 The design bearing strength (q_{dbs})shall be determined by multiplying the ultimate bearing strength (q_u) by an appropriate *strength reduction factor* for bearing strength (Φ_{bc}) from Subsection 2.1.2.

2.1.1.4 The ultimate bearing strength (q_u) is the pressure, exerted on the ground by the *building* foundation, which causes the ground to fail by mobilisation of all available shear strength. It shall be evaluated using the provisions in Section 2.2.

2.1.1.5 The ultimate bearing strength shall be based on the most adverse moisture and groundwater conditions likely to occur.

2.1.1.6 Founding depths in clay soils known to exhibit swelling and shrinking behaviour shall be chosen so that the underside of the foundation is beneath the zone of soil affected by shrinking and swelling caused by seasonal weather changes, and the root systems of nearby trees and shrubs.

2.1.1.7 Consideration shall be given to the possibility of any surcharge adjacent to a shallow foundation being removed during the life of the foundation, so reducing the available ultimate bearing strength.

2.1.1.8 Foundations subject to moment loading shall not be proportioned such that the point of application of the reaction force on the underside of the foundation is closer to the edge than B/6, for a rectangular foundation, or r/2, for a circular foundation.

2.1.1.9 When the loading is not normal to the foundation base, foundations shall be checked for failure by sliding in accordance with Section 2.3.

2.1.2 Strength reduction factors

2.1.2.1 *Strength reduction factors* to be applied to shallow foundation design shall be within the range given in Table 2.1.2.1. The designer shall nominate in the design the *strength reduction factors* chosen along with substantiation as to why the values chosen are considered appropriate.

> COMMENT: The value of the *strength reduction factor* used in design will depend on the knowledge of the site and the investigations undertaken. As a guide, the lower end of the range will generally be appropriate when a limited site investigation is undertaken, average geotechnical properties are used, published correlations are used to obtain design parameters, or there will be minimal *construction* control. The upper end of the range will generally be appropriate when a comprehensive site investigation and laboratory testing is undertaken, geotechnical properties are chosen conservatively, site specific correlations are used for design parameters, and there will be careful *construction* control.

Table 2.1.2.1: Strength reduction factors for shallow foundation design

Paragraph 2.1.2.1

Load combination[1]	Strength reduction factor range
For bearing (ϕ_{bc}) and passive earth pressure (ϕ_{pp}):	
Load combinations involving earthquake overstrength	0.80 to 0.90
All other load combinations	0.45 to 0.60
For sliding (ϕ_{sl}): All load combinations, including earthquake overstrength	0.80 to 0.90

Note: (1) Φ_{bc} is the *strength reduction factor* for bearing strength. Φ_{pp} is the *strength reduction factor* for resistance derived from passive earth pressure. Φ_{sl} is the *strength reduction factor* for sliding resistance.

2.2 Ultimate limit state bearing strength for shallow foundations

2.2.1 Determining the ultimate bearing strength

2.2.1.1 The calculations in this section apply to foundations of any size. The formulae are limited to soil profiles that for a depth beneath the underside of the foundation of at least two times the foundation width can be represented with single values for the density, angle of shearing resistance, cohesion, and if appropriate, undrained shear strength.

2.2.1.2 The ultimate bearing strength for a shallow foundation subject to vertical, shear, and moment loading shall be determined in accordance with in Equation 2.1.

Equation 2.1:

General expression: $q_u = c\lambda_{cs}\lambda_{cd}\lambda_{ci}\lambda_{cg}N_c + q\lambda_{qs}\lambda_{qd}\lambda_{qi}\lambda_{qg}N_q + 0.5\Gamma B'\lambda_{\gamma s}\lambda_{\gamma d}\lambda_{\gamma i}\lambda_{\gamma g}N_\gamma$

For undrained analysis (ϕ = 0): $q_u = s_u\lambda_{cs}\lambda_{cd}\lambda_{ci}\lambda_{cg}N_c + q\lambda_{qg}$

For drained analysis: $q_u = c'\lambda_{cs}\lambda_{cd}\lambda_{ci}\lambda_{cg}N_c + q'\lambda_{qs}\lambda_{qd}\lambda_{qi}\lambda_{qg}N_q + 0.5\gamma' B'\lambda_{\gamma s}\lambda_{\gamma d}\lambda_{\gamma i}\lambda_{\gamma g}N_\gamma$

where:

q_u is the ultimate bearing strength (kPa); and

N_c, N_q, N_γ are bearing strength factors as determined in accordance with Subsection 2.2.3; and

c is cohesion (kPa); and

c' is the effective stress cohesion (kPa); and

q is the vertical total stress in ground adjacent to the foundation at depth D_f (kPa); and

s_u is the undrained shear strength (kPa); and

q' is the vertical effective stress (σ'_v) in ground adjacent to the foundation at depth D_f (kPa); and

σ'_v is the vertical effective stress at a given depth in the soil profile equal to $\sum \gamma_i T_i - u$ where γ_i is the unit weight and T_i is the thickness of the ith soil layer above the depth at which σ'_v is required (kPa); and

Γ is γ when the water table is deeper than 2B beneath the underside of the foundation and γ' when the water table is above this; and

γ is the soil unit weight (kN/m^3); and

γ' is the soil unit weight required for effective stress analysis for soil beneath the water table and equal to $\gamma - \gamma_w$ (kN/m^3); and

γ_w is the water unit weight (kN/m^3); and

B' is the effective breadth of the foundation determined in accordance with Subsection 2.2.1.3; and

ϕ is the angle of shearing resistance (degrees); and

λ_{cs}, λ_{qs}, $\lambda_{\gamma s}$, λ_{cd}, λ_{qd}, $\lambda_{\gamma d}$, λ_{ci}, λ_{qi}, $\lambda_{\gamma i}$, λ_{cg}, λ_{qg}, $\lambda_{\gamma g}$ are the factors given in Subsection 2.2.4.

2.2.1.3 For sands with relative densities less than 40% and clays having liquidity indices greater than 0.7, the bearing strength shall be evaluated using 0.67c for cohesion and $\tan^{-1}(0.67\tan\phi)$ for the angle of shearing resistance.

COMMENT: The formulae in this section assume a general shear failure of the soil. However, for the soils specified in Paragraph 2.2.1.3 a local shear failure is likely.

2.2.2 Effective dimensions of the foundation

2.2.2.1 For a rectangular foundation, the effective breadth of the foundation (B'), the effective length of the foundation (L'), and effective area of the foundation (A') are determined in accordance with Equation 2.2, Equation 2.3, and Equation 2.4 as illustrated in Figure 2.2.2.1.

Equation 2.2: B' = the smaller of $2(X + e_b)$ and $2(B – X – e_b)$

Equation 2.3: L' = the smaller of $2(Y + e_l)$ and $2(L – Y – e_l)$

Equation 2.4: $A' = B'L'$

where:

B' is the effective breadth of the foundation (m); and
L' is the effective length of the foundation (m); and
A' is the effective area of the foundation (m^2); and
B is the foundation breadth (m); and
L is the foundation length (m); and
X the distance from the edge of the foundation, along the x-axis, to the point of application of the design vertical foundation load V (m); and
x is the axis through design vertical foundation load V in direction of foundation breadth. The axis starts at the foundation edge and is positive in the direction towards V; and
Y the distance from the edge of the foundation, along the y-axis, to the point of application of the design vertical foundation load V (m); and
y is the axis through design vertical foundation load V in direction of foundation length. The axis starts at the foundation edge and is positive in the direction towards V; and
e_b is M_l/V and is positive when R is further along the x axis than V (m); and
e_l is M_b/V and is positive when R is further along the y axis than V (m); and
R is the reaction on underside of foundation and equal to q_dA' (kN); and
M_l is the design moment applied about an axis parallel to the length direction of the foundation (kNm); and
M_b is the design moment applied about an axis parallel to the breadth direction of the foundation (kNm); and
V is the design factored vertical foundation load (kN); and
q_d is the design bearing pressure and equal to V/A' (kPa).

2.2.2.2 For a circular foundation, the effective area of the foundation (A') is determined for an equivalent rectangle of Length L' and breath B' in accordance with Equation 2.5 and as illustrated in Figure 2.2.2.2.

Equation 2.5: $A' = 2r^2 \left[\cos^{-1}(\xi) - \xi\sqrt{1-\xi^2}\right]$ for an equivalent rectangle of Length L' and breath B'

where:

A' is the effective area of the foundation (m^2); and

$B' = \left(\frac{1-\xi}{1+\xi}\right)^{0.25}\sqrt{A'}$; and

$L' = \left(\frac{1+\xi}{1-\xi}\right)^{0.25}\sqrt{A'}$; and

r is the radius of a circular foundation (m); and

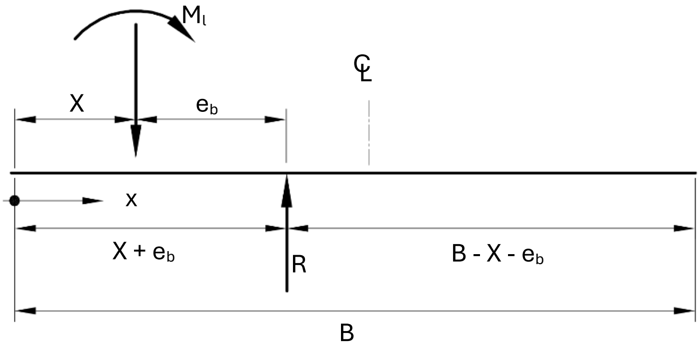
$\xi = \frac{e_c + Z - r}{r}$ when $e_c + Z \geq r$, or $= \frac{r - e_c - Z}{r}$ otherwise; and

$\cos^{-1}(\xi)$ is in radians; and
Z the distance from the edge of a circular foundation, along the z-axis, to the point of application of the design vertical foundation load V (m); and

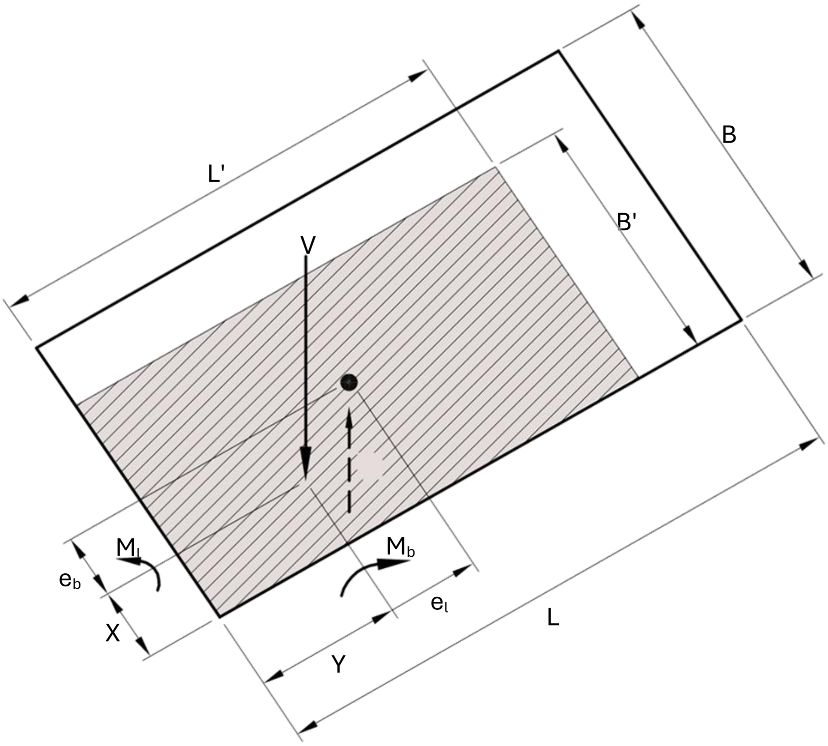
z is the axis through the centre of a circular foundation and the design vertical foundation load V. The axis starts at the foundation edge and is positive in the direction towards V.
e_c is M_c/V and is positive when R is further along the z-axis than V (m); and
M_c is the design moment applied to a circular footing (kNm); and
R is the reaction on underside of foundation and equal to $q_d A'$ (kN); and
V is the design factored vertical foundation load (kN).

Figure 2.2.2.1: Bearing strength stress block for a shallow rectangular foundation subject to vertical load and moment

Paragraph 2.2.2.1



(a) Cross-section through foundation width



(b) Plan showing the effective area of the foundation

Notes:

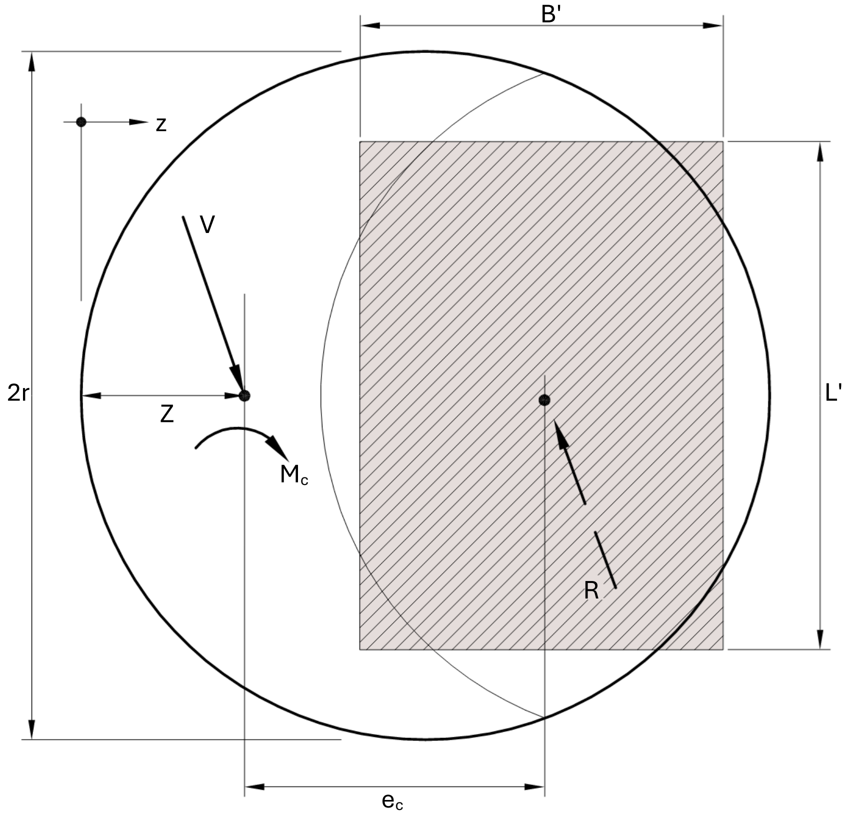
(1) Section (a) above drawn through foundation width. Section through foundation length similar.

(2) B' is given in Equation 2.2. L' is given in Equation 2.3.

(3) M can be applied anywhere on the foundation and does not have to be applied at the location of V.

Figure 2.2.2.2: Effective foundation area for a circular foundation subject to vertical load and moment

Paragraph 2.2.2.2



Note: The effective area of the foundation (A') shall be represented by an equivalent rectangle of length L' and breadth B' as per Equation 2.5.

2.2.3 Bearing strength factors

2.2.3.1 The bearing strength factors shall be obtained from Figure 2.2.3.1 or from Equation 2.6, Equation 2.7, and Equation 2.8.

Equation 2.6: $N_q = e^{\pi \tan \phi} \tan^2\left(45° + \frac{\phi}{2}\right)$

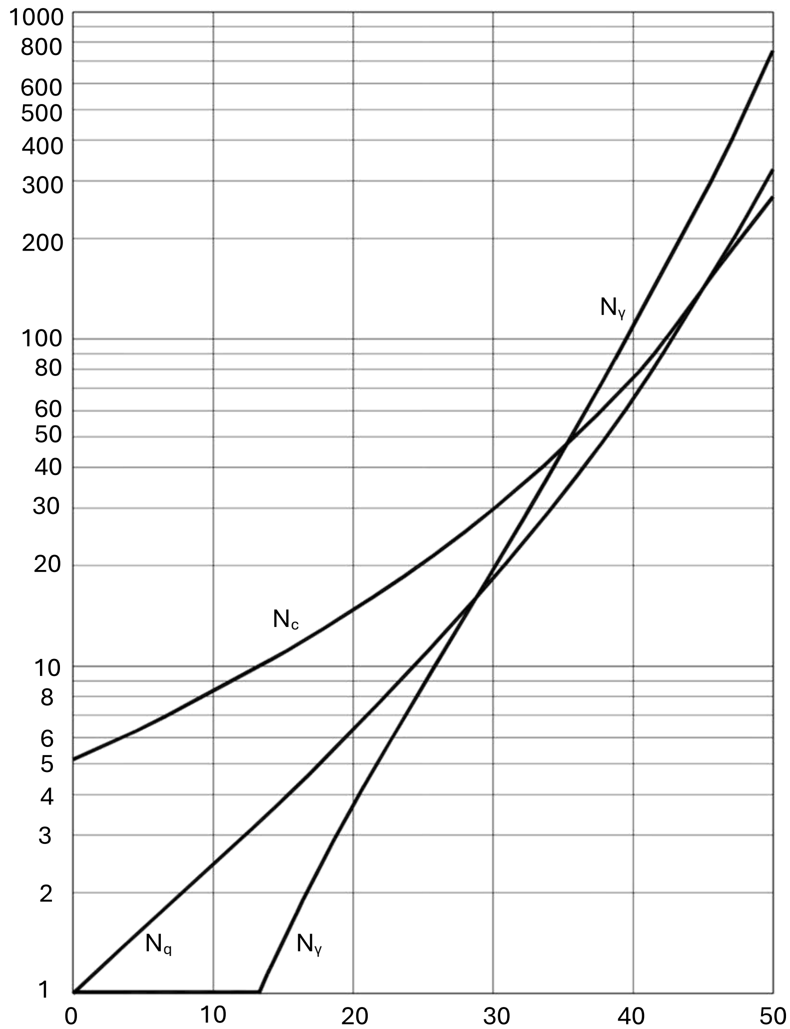
Equation 2.7: $N_c = \left(N_q - 1\right) \cot \phi$ for $\phi > 0$ and
$N_c = 5.14$ for $\phi = 0$

Equation 2.8: $N_\gamma = 2\left(N_q - 1\right) \tan \phi$

where:
N_c, N_q, N_γ are bearing strength factors; and
e is the mathematical constant = 2.7183; and
ϕ is the angle of shearing resistance (degrees).

Figure 2.2.3.1: Bearing strength factors

Paragraphs 2.2.3.1 and 3.2.3.2



Angle of shearing resistance ϕ (degrees)

For $\phi = 0$: $N_c = 5.14$, $N_q = 1$, $N_\gamma = 0$

2.2.4 Shape, depth, load inclination, and ground inclination factors

2.2.4.1 The shape factors (λ_{cs}, λ_{qs} and $\lambda_{\gamma s}$) shall be determined in accordance with Equation 2.9, Equation 2.10, and Equation 2.11.

Equation 2.9: $$\lambda_{cs} = 1+\left(\frac{B'}{L'}\right)\left(\frac{N_q}{N_c}\right)$$

Equation 2.10: $$\lambda_{qs} = 1+\left(\frac{B'}{L'}\right)\tan\phi$$

Equation 2.11: $$\lambda_{\gamma s} = 1-0.4\left(\frac{B'}{L'}\right)$$

where:

λ_{cs}, λ_{qs}, $\lambda_{\gamma s}$ are the shape factors; and
B' is the effective foundation breadth determined in accordance with Subsection 2.2.1.3; and
L' is the effective foundation length determined in accordance with Subsection 2.2.1.3; and
N_c, N_q, N_γ are bearing strength factors determined in accordance with Subsection 2.2.3; and
ϕ is the angle of shearing resistance (degrees).

2.2.4.2 The depth factors (λ_{cd}, λ_{qd} and $\lambda_{\gamma d}$) shall be determined in accordance with Equation 2.12, Equation 2.13, and Equation 2.14.

Equation 2.12:

$$\lambda_{cd} = 1+0.4\left(\frac{D_f}{B'}\right) \quad \text{for } \phi = 0 \text{ and } \frac{D_f}{B'} \le 1\text{ ; and}$$

$$\lambda_{cd} = 1+0.4\tan^{-1}\left(\frac{D_f}{B'}\right) \quad \text{for } \phi = 0 \text{ and } \frac{D_f}{B'} > 1\text{ ; and}$$

$$\lambda_{cd} = \lambda_{qd} - \frac{(1-\lambda_{qd})}{N_q\tan\phi} \quad \text{for } \phi > 0$$

Equation 2.13:

$$\lambda_{qd} = 1+2\tan\phi(1-\sin\phi)^2\left(\frac{D_f}{B'}\right) \quad \text{for } \frac{D_f}{B'} \le 1\text{ ; and}$$

$$\lambda_{qd} = 1+2\tan\phi(1-\sin\phi)^2\tan^{-1}\left(\frac{D_f}{B'}\right) \quad \text{for } \frac{D_f}{B'} > 1$$

Equation 2.14: $\lambda_{\gamma d} = 1$ for all cases

where:

λ_{cd}, λ_{qd}, $\lambda_{\gamma d}$ are the depth factors; and
D_f is the depth to the underside of the foundation (m); and
B' is the effective breadth of the foundation determined in accordance with Subsection 2.2.1.3.
N_q is one of the bearing strength factors determined in accordance with Subsection 2.2.3; and
ϕ is the angle of shearing resistance (degrees); and
$\tan^{-1}$ is in radians.

2.2.4.3 The load inclination factors (λ_{ci}, λ_{qi}, and $\lambda_{\gamma i}$) shall be determined in accordance with Equation 2.15, Equation 2.16, and Equation 2.17.

Equation 2.15:

$$\lambda_{ci} = 0.5\left(1+\sqrt{1-\frac{H}{A's_u}}\right) \quad \text{for } \phi = 0\text{; and}$$

$$\lambda_{ci} = \frac{\lambda_{qi}N_q-1}{N_q-1} \quad \text{for } \phi > 0$$

Equation 2.16:

$$\lambda_{qi} = 1 \quad \text{for } \phi = 0\text{; and}$$

$$\lambda_{qi} = 1-\frac{H_{uf}}{(V_{uf}+A'c'\cot\phi')} \quad \text{for } \phi > 0 \text{ and horizontal loading parallel to L'; and}$$

$$\lambda_{qi} = \left(1-\frac{0.7H_{uf}}{V_{uf}+A'c'\cot\phi'}\right)^3 \quad \text{for } \phi > 0 \text{ and horizontal loading parallel to B'}$$

Equation 2.17:

$$\lambda_{\gamma i} = 1-\frac{H_{uf}}{(V_{uf}+A'c'\cot\phi')} \quad \text{for } \phi > 0 \text{ and horizontal loading parallel to L'; and}$$

$$\lambda_{\gamma i} = \left(1-\frac{H_{uf}}{V_{uf}+A'c'\cot\phi'}\right)^3 \quad \text{for } \phi > 0 \text{ and horizontal loading parallel to B'}$$

where:

λ_{ci}, λ_{qi}, $\lambda_{\gamma i}$ are the load inclination factors; and

H is the design horizontal load and the resultant of the factored horizontal forces applied to the foundation (kN); and

A' is the effective area of the foundation determined in accordance with Subsection 2.2.1.3; and

s_u is the undrained shear strength (kPa); and

N_q is one of the bearing strength factors determined in accordance with Subsection 2.2.3; and

H_{uf} unfactored horizontal foundation load (kN); and

V_{uf} is the unfactored vertical foundation load (kN); and

c' is the effective stress cohesion (kPa); and

ϕ is the angle of shearing resistance (degrees).

2.2.4.4 The ground inclination factors (λ_{cg}, λ_{qg}, and $\lambda_{\gamma g}$) shall be determined in accordance with Equation 2.18, Equation 2.19, and Equation 2.20. For inclined ground, the permitted slope (angle ω below the horizontal) depends on soil angle of shearing resistance ϕ and the distance D_e between the foundation and the slope face.

Equation 2.18: $\lambda_{cg} = 1$ for horizontal ground, or inclined ground when $D_e \geq 2B$; and

$$\lambda_{cg} = 1 - \frac{\omega\left(1 - \frac{D_e}{2B}\right)}{150°}$$ for inclined ground when $D_e < 2B$

Equation 2.19: $\lambda_{qg} = 1$ for horizontal ground, or inclined ground when $D_e \geq 2B$; and

$$\lambda_{qg} \left(1 - \tan\left(\omega\left(1 - \frac{D_e}{2B}\right)\right)\right)^2$$ for inclined ground when $D_e < 2B$

Equation 2.20: $\lambda_{\gamma g} = 1$ for horizontal ground, or inclined ground when $D_e \geq 2B$; and

$$\lambda_{\gamma g} = \left(1 - \tan\left(\omega\left(1 - \frac{D_e}{2B}\right)\right)\right)^2$$ for inclined ground when $D_e < 2B$

where:

λ_{cg}, λ_{qg}, $\lambda_{\gamma g}$ are the ground inclination factors; and

D_e is the minimum horizontal distance from the edge of the underside of the foundation to the face of an adjacent downward slope (m); and

B is the foundation breadth (m); and

ω is the slope, below horizontal, of the ground adjacent to the edge of the foundation (degrees).

ϕ is the angle of shearing resistance (degrees). For drained analysis when $\phi \geq 0$, ω shall not be > ϕ. For undrained analysis when $\phi = 0$, ω shall not be > 45°.

2.3 Ultimate limit state sliding resistance

2.3.1 Determining the sliding resistance

2.3.1.1 The ultimate sliding resistance shall comprise the sum of the ultimate sliding strength between the base of the foundation and the ground, and any available passive earth pressure in the direction of sliding at the side of the foundation.

2.3.1.2 Passive earth pressure shall not be considered if:

a) for foundations in clay soils, it is possible that the clay could shrink away from the vertical faces of the foundation; or

b) the possibility exists that the soil in front of the foundation may be removed by erosion or by building or landscaping work in the future.

2.3.1.3 The ultimate sliding strength shall be determined using Equation 2.21.

Equation 2.21: $S = c'A' + V' \cdot \tan\delta'$ for drained conditions

$S = A' s_u$ for undrained conditions

where:
S is the ultimate shear strength between the base of the foundation and the ground (kN); and
c' is the effective stress cohesion (kPa); and
A' is the effective area of the foundation determined in accordance with Subsection 2.2.2; and
V' is the effective design factored vertical load and equal to $V – u_f A'$ (kN); and
δ' is determined in accordance with Paragraph 2.3.1.4; and.
V is the design factored vertical foundation load (kN); and
u_f is the pore water pressure at depth D_f.(kPa); and
ϕ' is the effective stress angle of shearing resistance (degrees).

2.3.1.4 The value of δ' shall be taken as the angle of shearing resistance (ϕ') of the foundation soil for cast-in-situ concrete foundations and 0.67 ϕ' for smooth precast foundations.

2.3.1.5 The design horizontal load (H(shall not exceed the design sliding resistance as given in Equation 2.22.

Equation 2.22: $H \leq \Phi_{sl} S + \Phi_{pp} P_p$

where:
H is the design horizontal load and the resultant of the factored horizontal forces applied to the foundation (kN); and
Φ_{sl} is the *strength reduction factor* for sliding resistance (refer to Subsection 2.1.2); and
S is the ultimate shear strength between the base of the foundation and the ground (kN); and
Φ_{pp} is the *strength reduction factor* for resistance derived from passive earth pressure (refer to Subsection 2.1.2); and
P_p is the ultimate lateral resistance derived from passive earth pressure (kN).

Part 3. Pile foundations

3.1 Demonstrating compliance

3.1.1 Overview

3.1.1.1 The ultimate axial compressive pile strength for a single pile shall be determined using either one or both of the following methods:

a) geotechnical calculation; and/or

b) static load testing.

> COMMENT: Where piles are driven, a driving formula, such as the Hiley Formula, may provide a useful means of assessing the comparative strength of the individual piles at a particular site

3.1.1.2 When using geotechnical calculation, the ultimate axial compressive pile strength is the sum of the ultimate pile point-bearing resistance and the shaft resistance (V_{su}).

3.1.1.3 When determined by static load testing, the ultimate axial compressive pile strength shall be taken as no more than the load that produces a penetration or pile settlement of 0.1 times the:

a) *nominal pile width* for driven piles; and

b) bell diameter for belled piles,

c) estimated minimum bulb diameter for bulbed piles.

3.1.1.4 Suitable procedures for static load testing are described in AS 2159 Section 8, ASTM D1143 and BS 8004 Section 7.5.

3.1.1.5 The design pile vertical or lateral strength of a single pile or pile group shall be determined by multiplying the ultimate strength by the appropriate *strength reduction factor* (refer to Subsection 3.1.2). The design strength shall be greater than the applied factored loads.

3.1.2 Strength reduction factors

3.1.2.1 *Strength reduction factors* for design of ultimate vertical and lateral strengths in pile foundations shall be within the range given in Table 3.1.2.1. The designer shall nominate in the design the *strength reduction factors* chosen along with substantiation as to why the values chosen are considered appropriate.

> COMMENT: The value of the strength reduction factor used in design will depend on the designer's knowledge of the site and the investigations undertaken. As a guide the lower end of the range will generally be appropriate when a limited site investigation is undertaken, average geotechnical properties are used, published correlations are used to obtain design parameters or there will be minimal construction control. The upper end of the range will generally be appropriate when a comprehensive site investigation and laboratory testing is undertaken, geotechnical properties are chosen conservatively, site specific correlations are used for design parameters and there will be careful construction control.

Table 3.1.2.1: Strength reduction factors for deep foundation design

Paragraph 3.1.2.1

Method of assessment of ultimate geotechnical strength for load combinations not involving earthquake overstrength	Range of values of ϕ_{pc}
Static load testing to failure	0.65 to 0.85
Static proof (not to failure) load testing	0.70 to 0.90
Static analysis using CPT (Cone Penetrometer Test) data	0.45 to 0.65
Static analysis using SPT (Standard Penetrometer Test) data in cohesionless soils	0.40 to 0.55
Static analysis using laboratory data for cohesive soils	0.45 to 0.55
Method of assessment of ultimate geotechnical strength for load combinations including earthquake overstrength	0.80 to 0.90

3.1.3 Downdrag

3.1.3.1 Downdrag may be generated when a pile shaft passes through a compressible soil layer. Downdrag shall be considered as dead load applied to the parts of the pile below the compressible layer. It shall be added to the imposed loadings and factored accordingly.

3.1.4 Pile types

3.1.4.1 Precast concrete piles, including prestressed piles, shall withstand without damage or significant cracking, the stresses arising from manufacture, handling and transportation, in addition to those arising from driving and imposed loadings.

3.1.4.2 Belled bases of cast-in-situ concrete piles shall be no less than 100 mm thick at the edge of the required base and, unless the bell is reinforced, the conical surfaces shall slope at an angle from the horizontal of no less than 60°.

3.1.4.3 The design of steel piles shall be based on the nett steel section after deducting an appropriate thickness for future loss by corrosion. This verification method does not describe a means of determining the amount of corrosion.

> COMMENT: The amount deducted needs to take account of the aggressiveness of the soil. Further guidance can be found in AS 2159 Section 6.3.

3.1.4.4 Allowance for corrosion loss need not be made for steel encased in concrete provided cover to the steel is no less than:

a) 30 mm for prestressed concrete; and

b) 50 mm for precast concrete; and

c) 75 mm for cast-in-situ concrete.

3.1.4.5 Timber piles shall comply with:

a) Subsection 3.5.1 of the Building Product Specifications; and

b) either:

   i) Subsection 2.1.2 of the Building Product Specifications, or

   ii) NZS 3603.

3.2 Ultimate vertical strength of single piles

3.2.1 Vertical strength

3.2.1.1 The vertical pile strength is calculation using Equation 3.1.

Equation 3.1: $V_u = V_{su} + V_{bu}$

where:
V_u is the vertical pile strength (kN); and
V_{su} is the ultimate shaft resistance (kN) as calculated in Subsection 3.2.4; and
V_{bu} is ultimate base resistance (kN) as calculated in Subsection 3.2.2.

3.2.2 Base resistance

3.2.2.1 The undrained base resistance of piles in cohesive soil is calculated using Equation 3.2.

Equation 3.2: $V_{bu} = (9s_u + q)A_b$

where:
V_{bu} is ultimate base resistance (kN); and
s_u is the undrained shear strength (kPa); and
q is the vertical stress in the soil at a depth equal to the base of the pile shaft, total stress for undrained analysis, and effective stress for drained analysis (kPa); and
A_b is the area of pile base (m^2).

3.2.2.2 The drained base resistance, when the soil is sufficiently uniform to be represented by single values of c', ϕ', s_u and γ for a distance of three pile shaft diameters above and below the pile base, is given in Equation 3.3.

Equation 3.3: $V_{bu} = \left(9c' + q'N_q + 0.6D_b\Gamma N_\gamma\right)A_b$

where:
V_{bu} is ultimate base resistance (kN); and
c' is the effective stress cohesion (kPa); and
q' is the vertical effective stress (kPa); and
N_q, N_γ are bearing strength factors as determined in accordance with Subsection 3.2.3; and
D_b is the diameter of the pile base (m); and
Γ is γ when the water table is deeper than 2B beneath the underside of the pile foundation and γ' when the water table is above this; and
B is the pile foundation breadth (m); and
γ is the unit weight of the soil in which the pile is embedded, chosen to give the total stresses for undrained loading in cohesive soil and effective stresses for drained loading (γ' beneath the water table)(kN/m^3).

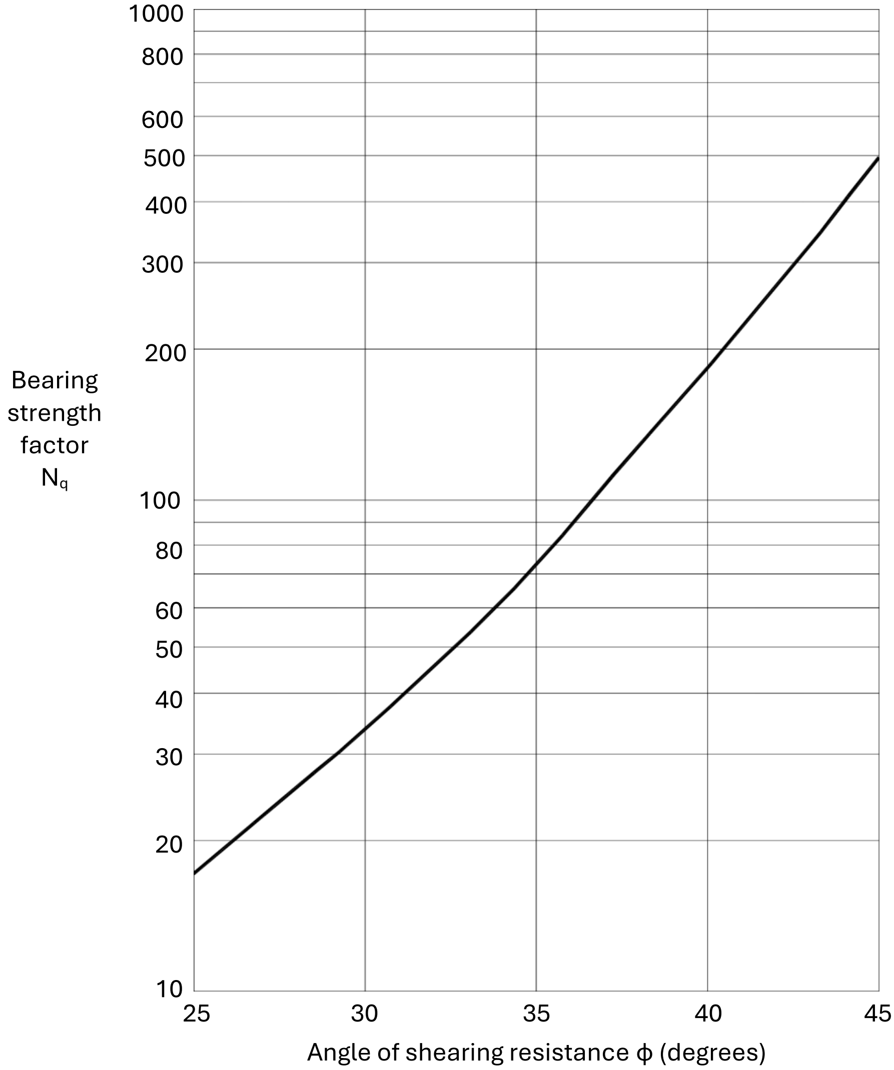
3.2.3 Bearing strength factors

3.2.3.1 The bearing strength factor N_q shall be obtained from Figure 3.2.3.1.

3.2.3.2 The bearing strength factor N_γ shall be obtained from Figure 2.2.3.1 or Equation 2.8.

Figure 3.2.3.1: N_q values for pile foundations

Paragraph 3.2.3.1



3.2.4 Shaft resistance

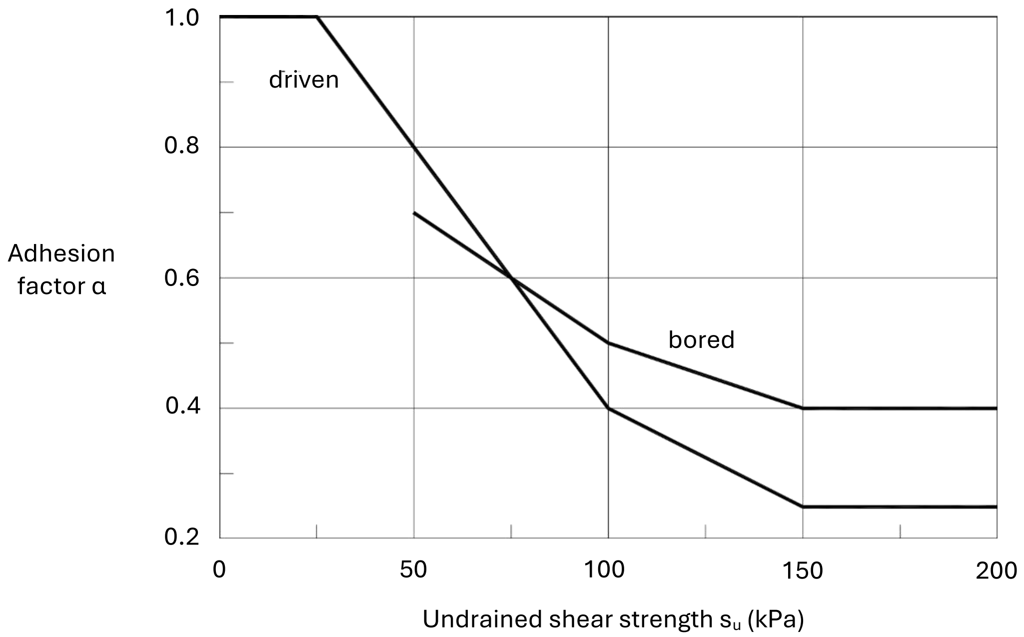
3.2.4.1 The shaft resistance for undrained loading of piles in cohesive soils is calculated using Equation 3.4.

Equation 3.4: $V_{su} = (c_a)_{average}\ C{\cdot}L$

where:
V_{su} is the ultimate shaft resistance (kN); and
$(c_a)_{average}$ is the undrained adhesion (total stress) at the soil/ shaft interface in a clay soil, or the adhesion at the boundary of a pile group, and is equal to αs_u taken as the average value over the length of the pile shaft(kPa); and
α is the adhesion factor given in Figure 3.2.4.1 for both driven and bored piles; and
s_u is the undrained shear strength (kPa); and
C is the circumference of the pile shaft (m); and
L is the length of the pile shaft (m).

Figure 3.2.4.1: Adhesion factor for piles in cohesive soils

Equation 3.4



3.2.4.2 The shaft resistance for drained loading is calculated using Equation 3.5.

Equation 3.5: $V_{su} = \{(c'_a)_{average} + (\sigma'_v K_o \tan\delta')_{average}\} C \cdot L$ for piles in cohesive soils

$V_{su} = \{(\sigma'_v K_s \tan\delta')_{average}\} C \cdot L$ for driven piles in cohesionless soils

where:
V_{su} is the ultimate shaft resistance (kN); and
$(c'_a)_{average}$ is the drained (effective stress) adhesion at the soil/shaft interface in a cohesive soil, or the adhesion at the boundary of a pile group taken as the average value over the length of the pile shaft (kPa); and
σ'_v is the vertical effective stress at a given depth in the soil profile equal to $\sum \gamma_i T_i$ - u where γ_i is the unit weight and T_i is the thickness of the ith soil layer above the depth at which σ'_v is required (kPa); and
K_o is the coefficient of earth pressure at rest and equal to 1 – sinϕ' for loose sand and normally consolidated clay, and $(1 - \sin\phi')\sqrt{OCR}$ for over-consolidated soils; and

ϕ' is the effective stress angle of shearing resistance (degrees); and
OCR is the over-consolidation ratio being the previous maximum effective stress/current effective stress; and
K_s is a factor that expresses the horizontal effective stress at the pile/soil interface in terms of the vertical effective stress as given in Table 3.2.4.2.
δ' is taken from Table 3.2.4.2; and
$(\sigma'_v K_o \tan\delta')_{average}$ is the average value taken over the area of the pile shaft.

Table 3.2.4.2: Values of δ' and K_s for pile shafts

Equation 3.5 and Equation 3.32

Pile material	δ'	K_s when R_d < 40%(1)	K_s when R_d ≥ 40%(1)
Steel	20°	0.5	1.0
Concrete	3ϕ'/4	1.0	2.0
Timber	2ϕ'/3	1.5	4.0

Note: (1) The relative density (R_d) is measured in accordance with NZS 4402 Test 4.2.3.

3.3 Column action

3.3.1 Column behaviour of piles

3.3.1.1 Piles that stand unbraced in ground, water, or other material incapable of providing lateral support, shall be designed as columns.

3.3.1.2 For a column partly embedded in the ground, the effective length is dependent upon the position of end restraint, which in turn is dependent upon the nature of the ground. End restraint shall be assumed at a depth of no less than:

a) 3 times the *nominal pile width* in very stiff soil; and

b) 6 times the *nominal pile width* in stiff soil; and

c) 9 times the *nominal pile width* in other soil conditions.

3.3.1.3 Clays with an undrained shear strength greater than or equal to 100 kPa, and sands with a relative density greater than or equal to 50% shall be regarded as very stiff soil.

3.3.1.4 Clays with an undrained shear strength between 50 and 100 kPa, and for sands with a relative density between 30 and 50% shall be regarded as stiff soil.

3.4 Ultimate lateral strength of single piles

3.4.1 Classification of pile heads

3.4.1.1 In this section, the terms “free head” and “restrained head” pile are used. Free head piles are classified as short and long. Restrained head piles are classified as short, intermediate and long.

3.4.1.2 A free head pile has no restriction against head rotation when lateral displacement occurs. For a short free head pile, the magnitude of the maximum bending moment in the embedded shaft is less than the ultimate moment strength of the pile shaft, and the ultimate strength is controlled by the embedment length of the pile shaft. The strength of a long free head pile is controlled by the ultimate moment strength of the pile shaft and not by the embedded length.

3.4.1.3 For a restrained head pile subject to lateral displacement, the head rotation is constrained at the pile head by a fixing moment. A short pile is one in which the head moment and the maximum pile shaft moment are less than the ultimate moment strength of the pile section. For an intermediate length restrained head pile the head moment is equal to the ultimate strength of the pile shaft and elsewhere the shaft moments are less than M_{ult}. For a long restrained head pile the head moment and the maximum pile shaft moment each have a magnitude of M_{ult}.

3.4.1.4 A summary of the relevant paragraphs in this section for the various conditions is provided in Table 3.4.1.4.

Table 3.4.1.4: Overview of relevant paragraphs for different conditions and pile classifications

Paragraph 3.4.1.4

Soil condition	Drainage condition	Pile classification	Relevant paragraph
Cohesive soils having a constant undrained shear strength with depth	Undrained	Free head – short	3.4.2.1
		Free head – long	3.4.2.2
		Restrained – short	3.4.2.3
		Restrained – intermediate	3.4.2.4
		Restrained – long	3.4.2.5
Normally consolidated cohesive soil	Undrained	Free head – long	3.4.3.2
		Restrained – intermediate	3.4.3.3
		Restrained – long	3.4.3.4
Cohesionless soil	Drained	Free head – short	3.4.4.1
		Free head – long	3.4.4.2
		Restrained – short	3.4.4.3
		Restrained – intermediate	3.4.4.4
		Restrained – long	3.4.4.5

3.4.2 Undrained lateral strength of piles in cohesive soil having a constant undrained shear strength with depth

3.4.2.1 For short free head piles:

a) the ultimate lateral strength (H_u) of a short free head pile is calculated using Equation 3.6; and

b) the location, measured from the ground surface, of the maximum pile shaft moment (g_c) is calculated using Equation 3.7; and

c) the maximum moment (M_{max}) in the pile shaft is calculated using Equation 3.8; and

d) if M_{max} is greater than M_{ult} (the ultimate moment strength of the pile shaft), then the strength must be evaluated as for a long free head pile in accordance with Equation 3.6.

Equation 3.6: $$H_u = 9s_uD_s\left[\sqrt{2[(f + L)2 + (f + f_o)2]} - (L + 2f + f_o)\right]$$

Equation 3.7: $$g_c = \frac{H_u}{9s_uD_s} + f_o$$

Equation 3.8: $$M_{max} = H_u\left[\frac{H_u}{18s_uD_s} + f + f_o\right]$$

where:

H_u is ultimate lateral strength of a pile (kN); and

g_c is the position along the pile shaft at which yielding occurs for piles in over-consolidated clay (m);

M_{max} is the maximum moment in the pile shaft (kNm); and

s_u is the undrained shear strength (kPa); and

D_s is the diameter of the pile shaft (m); and

f is the distance above the ground surface at which the horizontal shear is applied and equal to M/H for a free head pile (m); and
f_o is the length of pile shaft assumed to be unsupported in cohesive soil and equal to $1.5D_s$ (m); and
M is the design moment applied to the pile head (factored applied moments) (kNm); and
H is the design horizontal load applied to the pile head (factored applied loads) (kN); and
L is the length of the pile shaft (m).

3.4.2.2 For long free head piles:

a) the ultimate lateral strength (H_u) of a long free head pile is calculated using Equation 3.6; and

b) the location, measured from the ground surface, of the maximum pile shaft moment (g_c) is calculated using Equation 3.7; and

c) the maximum moment (M_{max}) in the pile shaft is calculated using Equation 3.8.

Equation 3.9: $$H_u = 3s_uD_s\left[\sqrt{9(f + f_o)^2 + \frac{2M_{ult}}{s_uD_s}} - 3(f + f_o)\right]$$

where:
H_u is ultimate lateral strength of a pile (kN); and
s_u is the undrained shear strength (kPa); and
D_s is the diameter of the pile shaft (m); and

f is the distance above the ground surface at which the horizontal shear is applied and equal to M/H for a free head pile; and
M is the design moment applied to the pile head (factored applied moments) (kNm); and
H is the design horizontal load applied to the pile head (factored applied loads) (kN); and
f_o is the length of pile shaft assumed to be unsupported in cohesive soil and equal to $1.5D_s$ (m); and
M_{ult} is the ultimate moment strength of the pile shaft (kNm).

3.4.2.3 For short restrained head piles:

a) the ultimate lateral strength (H_u) of a short restrained head pile is calculated using Equation 3.10; and

b) the maximum moment (M_{max}) in the pile shaft is calculated using Equation 3.11; and

c) if M_{max} is greater than M_{ult} (the ultimate moment strength of the pile shaft), then the strength must be evaluated as for an intermediate restrained head pile in accordance with Paragraph 3.4.2.4.

Equation 3.10: $H_u = 9s_uD_s\ (L - f_o)$

Equation 3.11: $M_{max} = 0.5H_u(L + 2f + f_o)$

where:
H_u is ultimate lateral strength of a pile (kN); and
M_{max} is the maximum moment in the pile shaft (kNm); and
s_u is the undrained shear strength (kPa); and
D_s is the diameter of the pile shaft (m); and

f is the distance above the ground surface at which the restraint is applied (m); and
f_o is the length of pile shaft assumed to be unsupported in cohesive soil and equal to $1.5D_s$ (m); and
L is the length of the pile shaft (m).

3.4.2.4 For intermediate restrained head piles:

a) the ultimate lateral strength (H_u) of an intermediate restrained head pile is calculated using Equation 3.12; and

b) the location, measured from the ground surface, of the maximum pile shaft moment (g_c) is calculated using Equation 3.13; and

c) the maximum moment (M_{max}) in the pile shaft is calculated using Equation 3.14; and

d) if M_{max} is greater than M_{ult} (the ultimate moment strength of the pile shaft), then the strength must be evaluated as for a long restrained head pile in accordance with Equation 3.15.

Equation 3.12: $$H_u = 9s_uD_s\left[\sqrt{(L + 2f + f_o)^2 + \frac{4M_{ult}}{9s_uD_s}} - (L + 2f + f_o)\right]$$

Equation 3.13: $$g_c = \frac{H_u}{9s_uD_s} + f_o$$

Equation 3.14: $$M_{max} = H_u\left[\frac{H_u}{18s_uD_s} + f + f_o\right] - M_{ult}$$

where:
H_u is ultimate lateral strength of a pile (kN); and
g_c is the position along the pile shaft at which yielding occurs for piles in over-consolidated clay (m);
M_{max} is the maximum moment in the pile shaft (kNm); and
s_u is the undrained shear strength (kPa); and
D_s is the diameter of the pile shaft (m); and

f is the distance above the ground surface at which the restraint is applied (m); and
f_o is the length of pile shaft assumed to be unsupported in cohesive soil and equal to $1.5D_s$ (m); and
M_{ult} (the ultimate moment strength of the pile shaft) (kNm); and
L is the length of the pile shaft (m).

3.4.2.5 For long restrained head piles:

a) the ultimate lateral strength (H_u) of a long free head pile is calculated using Equation 3.15; and

b) the location, measured from the ground surface, of the maximum pile shaft moment (g_c) is calculated using Equation 3.13; and

c) the maximum moment (M_{max}) in the pile shaft is calculated using Equation 3.14.

Equation 3.15: $$H_u = 9s_uD_s\left[\sqrt{(f + f_o)^2 + \frac{4M_{ult}}{9s_uD_s}} - (f + f_o)\right]$$

where:
H_u is ultimate lateral strength of a pile (kN); and
s_u is the undrained shear strength (kPa); and
D_s is the diameter of the pile shaft (m); and

f is the distance above the ground surface at which the restraint is applied (m); and
f_o is the length of pile shaft assumed to be unsupported in cohesive soil and equal to $1.5D_s$ (m); and
M_{ult} is the ultimate moment strength of the pile shaft (kNm).

3.4.3 Undrained lateral strength of piles in normally consolidated cohesive soil

3.4.3.1 Normally consolidated cohesive soils have a linear increase in undrained shear strength with depth, starting with a value of zero at ground surface level. This subsection considers the rate of increase in undrained shear strength with depth as denoted by χ (kPa/m).

> COMMENT: Only the long free head pile and intermediate and long restrained head piles are considered. Short piles are not normally used in such material.

3.4.3.2 For long free head piles in normally consolidated cohesive soil,

a) the ultimate lateral strength (H_u) of a long free head pile is calculated by solving Equation 3.16; and

b) the location, measured from the ground surface, of the maximum pile shaft moment (g_l) is calculated using Equation 3.17.

Equation 3.16: $$H_u\left[\frac{2}{3}\sqrt{\frac{2H_u}{9D_s\chi}}+f\right]-M_{ult}=0$$

Equation 3.17: $$g_l=\sqrt{\frac{2H_u}{9D_s\chi}}$$

where:
H_u is ultimate lateral strength of a pile (kN); and
g_l is the position along the pile shaft at which yielding occurs for piles in normally consolidated clay (m);
D_s is the diameter of the pile shaft (m); and
χ is the rate of increase in undrained shear strength with depth (kPa/m); and
f is the distance above the ground surface at which the horizontal shear is applied and equal to M/H for a free head pile; and
M is the design moment applied to the pile head (factored applied moments) (kNm); and
H is the design horizontal load applied to the pile head (factored applied loads) (kN); and
M_{ult} is the ultimate moment strength of the pile shaft (kNm).

3.4.3.3 For intermediate restrained head piles in normally consolidated cohesive soil:

a) the ultimate lateral strength (H_u) of an intermediate restrained head pile is calculated using Equation 3.18; and

b) the location, measured from the ground surface, of the maximum pile shaft moment (g_l) is calculated using Equation 3.17; and

c) the maximum moment (M_{max}) in the pile shaft is calculated using Equation 3.19; and

d) if M_{max} is greater than M_{ult} (the ultimate moment strength of the pile shaft), then the strength must be evaluated as for a long restrained head pile in accordance with Equation 3.20.

Equation 3.18: $$H_u=\frac{3D_sL^3\chi}{2(f+L)}+\frac{M_{ult}}{f+L}$$

Equation 3.19: $$M_{max}=H_u\left[\frac{2}{3}\sqrt{\frac{2H_u}{9D_s\chi}}+f\right]-M_{ult}$$

where:
H_u is ultimate lateral strength of a pile (kN); and
M_{max} is the maximum moment in the pile shaft (kNm); and
D_s is the diameter of the pile shaft (m); and
χ is the rate of increase in undrained shear strength with depth (kPa/m); and
f is the distance above the ground surface at which the restraint is applied (m); and
M_{ult} (the ultimate moment strength of the pile shaft) (kNm); and
L is the length of the pile shaft (m).

3.4.3.4 For long restrained head piles in normally consolidated cohesive soil:

a) the ultimate lateral strength (H_u) of a long restrained head pile is calculated by solving Equation 3.20; and

b) the location, measured from the ground surface, of the maximum pile shaft moment (g_l) is calculated using Equation 3.17.

Equation 3.20: $$H_u\left[\frac{2}{3}\sqrt{\frac{2H_u}{9D_s\chi}}+f\right]-2M_{ult}=0$$

where:
H_u is ultimate lateral strength of a pile (kN); and
M_{max} is the maximum moment in the pile shaft (kNm); and
D_s is the diameter of the pile shaft (m); and
χ is the rate of increase in undrained shear strength with depth (kPa/m); and
f is the distance above the ground surface at which the restraint is applied (m); and
M_{ult} (the ultimate moment strength of the pile shaft) (kNm).

3.4.4 Drained lateral strength of piles in cohesionless soil

3.4.4.1 For short free head piles in cohesionless soil:

a) the ultimate lateral strength (H_u) of a short free head pile is calculated using Equation 3.21; and

b) the location, measured from the ground surface, of the maximum pile shaft moment (g_s) is calculated using Equation 3.22; and

c) the maximum moment (M_{max}) in the pile shaft is calculated using Equation 3.23.

Equation 3.21: $$H_u=\frac{K_pD_sL^3\gamma}{2(f+L)}$$

Equation 3.22: $$g_s=\sqrt{\frac{2H_u}{3K_p\gamma D_s}}$$

Equation 3.23: $$M_{max}=H_u\left[\frac{2}{3}\sqrt{\frac{2H_u}{3K_pD_s\gamma}}+f\right]$$

where:
H_u is ultimate lateral strength of a pile (kN); and
g_s is the position along the pile shaft at which yielding occurs for piles in sand (m);
M_{max} is the maximum moment in the pile shaft (kNm); and
K_p is the coefficient of passive earth pressure and equal to $(1 + \sin\phi')/(1 - \sin\phi')$; and
ϕ' is the effective stress angle of shearing resistance (degrees); and
D_s is the diameter of the pile shaft (m); and
γ is the unit weight of the soil in which the pile is embedded (kN/m^3); and
f is the distance above the ground surface at which the horizontal shear is applied and equal to M/H for a free head pile (m); and
M is the design moment applied to the pile head (factored applied moments) (kNm); and
H is the design horizontal load applied to the pile head (factored applied loads) (kN); and
L is the length of the pile shaft (m).

3.4.4.2 For long free head piles in cohesionless soil:

a) the ultimate lateral strength (H_u) of a long free head pile is calculated by solving Equation 3.24; and

b) the location, measured from the ground surface, of the maximum pile shaft moment (g_s) is calculated using Equation 3.22.

Equation 3.24: $H_u \left[\frac{2}{3}\sqrt{\frac{2H_u}{3K_p D_s \gamma}} + f\right] - M_{ult} = 0$

where:
H_u is ultimate lateral strength of a pile (kN); and
K_p is the coefficient of passive earth pressure and equal to (1 + sinϕ')/(1 – sin ϕ'); and
D_s is the diameter of the pile shaft (m); and
γ is the unit weight of the soil in which the pile is embedded (kN/m^3); and
f is the distance above the ground surface at which the horizontal shear is applied and equal to M/H for a free head pile (m); and
M_{ult} (the ultimate moment strength of the pile shaft) (kNm); and
M is the design moment applied to the pile head (factored applied moments) (kNm); and
H is the design horizontal load applied to the pile head (factored applied loads) (kN).

3.4.4.3 For short restrained head piles in cohesionless soil:

a) the ultimate lateral strength (H_u) of a short restrained head pile is calculated using Equation 3.25; and

b) the maximum moment (M_{max}) in the pile shaft is calculated using Equation 3.26; and

c) if M_{max} is greater than M_{ult} (the ultimate moment strength of the pile shaft), then the strength must be evaluated as for an intermediate restrained head pile in accordance with Paragraph 3.4.4.4.

Equation 3.25: $H_u = 1.5 K_p D_s L^2 \gamma$

Equation 3.26: $M_{max} = H_u \left[\frac{2}{3} L + f\right]$

where:
H_u is ultimate lateral strength of a pile (kN); and
M_{max} is the maximum moment in the pile shaft (kNm); and
K_p is the coefficient of passive earth pressure and equal to (1 + sinϕ')/(1 – sin ϕ'); and
ϕ' is the effective stress angle of shearing resistance (degrees); and
D_s is the diameter of the pile shaft (m); and
γ is the unit weight of the soil in which the pile is embedded (kN/m^3); and
f is the distance above the ground surface at which the horizontal shear is applied and equal to M/H for a free head pile (m); and
M is the design moment applied to the pile head (factored applied moments) (kNm); and
H is the design horizontal load applied to the pile head (factored applied loads) (kN); and
L is the length of the pile shaft (m).

3.4.4.4 For intermediate restrained head piles in cohesionless soil:

a) the ultimate lateral strength (H_u) of an intermediate restrained head pile is calculated using Equation 3.27; and

b) the location, measured from the ground surface, of the maximum pile shaft moment (g_s) is calculated using Equation 3.28; and

c) the maximum moment (M_{max}) in the pile shaft is calculated using Equation 3.29; and

d) if M_{max} is greater than M_{ult} (the ultimate moment strength of the pile shaft), then the strength must be evaluated as for an intermediate restrained head pile in accordance with Equation 3.30.

Equation 3.27: $H_u = \frac{K_p D_s L^3 \gamma}{2(f+L)} + \frac{M_{ult}}{f+L}$

Equation 3.28: $g_s = \sqrt{\frac{2H_u}{3K_p D_s \gamma}}$

Equation 3.29: $M_{max} = H_u \left[\frac{2}{3}\sqrt{\frac{2H_u}{3K_p D_s \gamma}} + f\right] - M_{ult}$

where:
H_u is ultimate lateral strength of a pile (kN); and
g_s is the position along the pile shaft at which yielding occurs for piles in sand (m);
M_{max} is the maximum moment in the pile shaft (kNm); and
K_p is the coefficient of passive earth pressure and equal to (1 + sinϕ')/(1 – sin ϕ'); and
ϕ' is the effective stress angle of shearing resistance (degrees); and
D_s is the diameter of the pile shaft (m); and
γ is the unit weight of the soil in which the pile is embedded (kN/m^3); and
f is the distance above the ground surface at which the horizontal shear is applied and equal to M/H for a free head pile (m); and
M_{ult} (the ultimate moment strength of the pile shaft) (kNm); and
M is the design moment applied to the pile head (factored applied moments) (kNm); and
H is the design horizontal load applied to the pile head (factored applied loads) (kN); and
L is the length of the pile shaft (m).

3.4.4.5 For long restrained head piles in cohesionless soil:

a) the ultimate lateral strength (H_u) of a intermediate restrained head pile is calculated by solving Equation 3.30; and
b) the location, measured from the ground surface, of the maximum pile shaft moment (g_s) is calculated using Equation 3.28; and
c) the maximum moment (M_{max}) in the pile shaft is calculated using Equation 3.29.

Equation 3.30: $H_u \left[\frac{2}{3}\sqrt{\frac{2H_u}{3K_p D_s \gamma}} + f\right] - 2M_{ult} = 0$

where:
H_u is ultimate lateral strength of a pile (kN); and
K_p is the coefficient of passive earth pressure and equal to (1 + sinϕ')/(1 – sin ϕ'); and
ϕ' is the effective stress angle of shearing resistance (degrees); and
D_s is the diameter of the pile shaft (m); and
γ is the unit weight of the soil in which the pile is embedded (kN/m^3); and
f is the distance above the ground surface at which the horizontal shear is applied and equal to M/H for a free head pile (m); and
M_{ult} (the ultimate moment strength of the pile shaft) (kNm); and
M is the design moment applied to the pile head (factored applied moments) (kNm); and
H is the design horizontal load applied to the pile head (factored applied loads) (kN).

3.5 Pile groups

3.5.1 Ultimate vertical strength of pile groups

3.5.1.1 The vertical strength of a pile group considered as a single block in a cohesive soil is calculating using:

a) Equation 3.31 for undrained vertical strength; and

b) Equation 3.32 for drained strength.

Equation 3.31: $V_B = (9s_u + q)B_G L_G + 2(B_G + L_G)L(c_a)_{average}$

Equation 3.32: $V_B = \left(c' + q'N_q + 0.6B_G \Gamma N_\gamma\right)B_G L_G + 2(B_G + L_G)L\left\{(c'_a)_{average} + (\sigma'_v K_o \tan\delta')_{average}\right\}$

where:

V_B is the ultimate strength of the block of soil enclosed within the pile group (kN); and
s_u is the undrained shear strength (kPa); and
q is the vertical stress in the soil at a depth equal to the base of the pile shaft, the total stress for undrained analysis, and the effective stress for drained analysis (kPa); and
B_G is the width (between pile extremities) of a pile group (m); and
L_G is the length (between pile extremities) of a pile group (m); and
L is the length of the pile shaft (m); and
$(c_a)_{average}$ is the adhesion at the boundary of a pile group and equal to αs_u and taken as the average value over the length of the pile shaft (kPa);
c' is effective stress cohesion (kPa); and
N_q, N_γ are bearing strength factors; and
Γ is γ when the water table is deeper than 2B beneath the underside of the pile foundation and γ' when the water table is above this; and
γ is the unit weight of the soil in which the pile is embedded, chosen to give the total stresses for undrained loading in cohesive soil and effective stresses for drained loading (γ' beneath the water table) (kN/m^3); and
$(c'_a)_{average}$ is the drained (effective stress) adhesion at the soil/shaft interface in a cohesive soil, or the adhesion at the boundary of a pile group taken as the average value over the length of the pile shaft (kPa).
σ'_v is the vertical effective stress at a given depth in the soil profile equal to $\sum \gamma_i T_i - u$ where γ_i is the unit weight and T_i is the thickness of the ith soil layer above the depth at which σ'_v is required (kPa); and
K_o is the coefficient of earth pressure at rest and equal to $1 - \sin\phi'$ for loose sand and normally consolidated clay, and $(1 - \sin\phi')\sqrt{OCR}$ for over-consolidated soils; and
ϕ' is the effective stress angle of shearing resistance (degrees); and
OCR is the over-consolidation ratio being the previous maximum effective stress/current effective stress; and
δ' is taken from Table 3.2.4.2; and
$(\sigma'_v K_o \tan\delta')_{average}$ is the average value taken over the area of the pile shaft.

3.5.1.2 The ultimate vertical strength of the group is determined using Equation 3.33.

Equation 3.33: $$\frac{1}{V_G^2} = \frac{1}{n^2 V_1^2} + \frac{1}{V_B^2}$$

where:

V_G is the ultimate strength of the group (kN); and
n is the number of piles in the group; and
V_1 is the ultimate strength of an individual pile in the group (kN)
V_B is the ultimate strength of the block of soil enclosed within the pile group (kN).

3.5.1.3 If only part of an embedded friction pile length is in satisfactory material, the surface area calculated as providing frictional resistance shall be limited to the surface areas in contact with that material.

3.5.2 Ultimate lateral strength of pile groups

3.5.2.1 If piles are spaced at centre to centre intervals of less than 4.0 times the *nominal pile width*, the ultimate lateral pile strength shall be reduced. The reduced value shall be calculated as a percentage of the ultimate lateral pile strength for an isolated pile by linear interpolation between the two values given in Table 3.5.2.1.

Table 3.5.2.1: Design lateral resistance for closely spaced piles

Paragraph 3.5.2.1

Pile spacing	% of isolated pile lateral resistance
4.0 x *nominal pile width*	100
1.0 x *nominal pile width* (palisade type wall)	25

Appendix A. References

For the purposes of Building Code compliance, the standards and documents referenced in this verification method must be the editions, along with their specific amendments, listed below.

Standards New Zealand		Where quoted
AS/NZS 1170.0:2004	Structural design actions – General principles Amendments 1, 2, 3, 4, 5	1.2.1.1, C.2.1.2
NZS 3603:1993	Timber structures standard Amendment 1, 2, 4	3.1.4.5(b)(ii)
NZS 4402.4.2.3:1988	Methods of testing soils for civil engineering purposes – Test 4.2.3: Soil compaction tests – Determination of the minimum and maximum dry densities and relative density of a cohesionless soil – Relative density	Table 3.2.4.2

These standards can be accessed from www.standards.govt.nz.

Standards Australia		Where quoted
AS 2159:1995	Rules for the design and installation of piling (known as the SAA Piling Code), Amendment 1	3.1.1.4

This standard can be accessed from www.standards.org.au.

British Standards Institution		Where quoted
BS 8004:1986	Code of practice for foundations	3.1.1.4

This standard can be accessed from www.standards.govt.nz.

American Society of Testing and Materials		Where quoted
ASTM D1143:1981	Test method for piles under static axial compressive load	3.1.1.4

This standard can be accessed from www.standards.org.au.

Appendix B. Definitions

These definitions are specific to this verification method. Other defined terms italicised within the definitions are provided in clause A2 of the Building Code.

Term	Definition
Alter	In relation to a *building*, includes to rebuild, re-erect, repair, enlarge, and extend the *building*.
Building	Has the meaning given to it by sections 8 and 9 of the Building Act 2004.
Construct	In relation to a *building*, includes to design, build, erect, prefabricate, and relocate the *building*; and construction has a corresponding meaning.
Nominal pile width	The least width of a pile in side view and is equal to the diameter in round piles.
Strength reduction factor	The factor by which the ultimate strength is multiplied to obtain the design strength.

Appendix C. Informative appendices

C.1 Site investigation

C.1.1 Overview

C.1.1.1 No specific site investigation procedures are given in this verification method. The following information is provided for guidance only.

C.1.1.2 The ground conditions at the *building* site should be investigated to the extent considered necessary, by a person with appropriate expertise and experience, to provide essential site data for design of the proposed *building*.

C.1.1.3 Preliminary investigations and detailed investigations may both need to be undertaken.

C.1.2 Preliminary investigation

C.1.2.1 The preliminary site assessment may include investigation of:

a) general land form, geology and any conditions likely to facilitate landslip, soil creep, shrinkage and expansion, or subsidence; and
b) information available from records of previous constructions, excavations, fillings, drains and concealed works, on and adjacent to the site; and
c) history and behaviour of neighbouring buildings and details of their foundation types, depths and loadings.
d) potential for flooding (refer to Building Code clause E1 Surface Water) and seasonal changes of soil characteristics; and
e) seasonal, tidal, or other natural groundwater changes; and
f) presence of corrosive soil, groundwater and effluents (refer to Verification Method F1/VM1).

C.1.3 Detailed investigation

C.1.3.1 Detailed investigation may include:

a) test bores and excavations; and
b) visual inspection; and
c) laboratory and field testing of soil and rock samples; and
d) advice from other people with relevant expertise.

C.1.4 Recording information

C.1.4.1 The description of the foundation material should be recorded. A suitable method for describing soil and rock is contained in “Guidelines for the field description of soils and rocks in engineering use” published by the New Zealand Geotechnical Society.

C.1.4.2 The site investigation record should include a site plan showing the locations of the test bores and excavations.

C.2 Foundation settlement

C.2.1 Serviceability limit state deformations

C.2.1.1 No specific method is given for determining foundation settlement in this verification method. The following information is provided for guidance only.

C.2.1.2 Foundation design should limit the probable maximum differential settlement over a horizontal distance of 6 m to no more than 25 mm under serviceability limit state load combinations of AS/NZS 1170.0, unless the structure is specifically designed to prevent damage under a greater settlement.

C.2.1.3 The basis for analysing settlement should be stated in the design. The analysis shall pay due consideration to:

a) size, shape and depth of the foundations; and
b) proximity and influence of proposed and existing foundations; and
c) variability of the ground; and
d) the presence of compressive or expansive materials; and
e) rate of consolidation; and
f) groundwater level; and
g) extent of fill placed and ground removed when constructing the foundation; and
h) likelihood of liquefaction, internal erosion, soil collapse or other special feature.

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ISBN (online) 978-1-991409-17-1