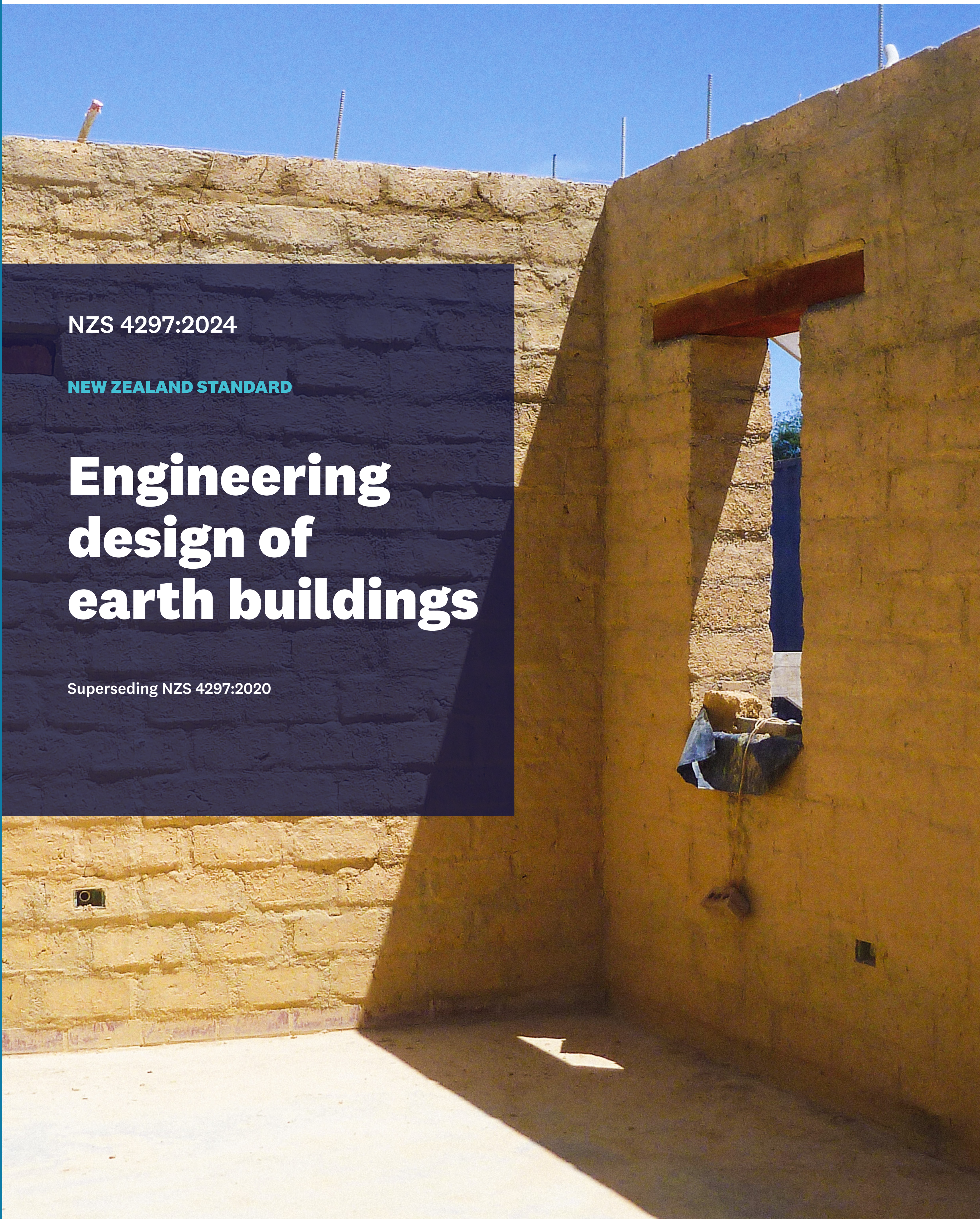
STANDARDS NEW ZEALAND
TE MANA TAUTIKANGA O AOTEAROA®



NZS 4297:2024

NEW ZEALAND STANDARD

Engineering design of earth buildings

Superseding NZS 4297:2020

NZS 4297:2024

Single User PDF Terms & Conditions

COMMITTEE REPRESENTATION

This standard was prepared by the P4297-99 Earth Buildings Committee. The membership of the committee was approved by the New Zealand Standards Approval Board and appointed by the New Zealand Standards Executive under the Standards and Accreditation Act 2015.

The committee consisted of representatives of the following nominating organisations:

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Alan Drayton	New Zealand Certified Builders Association
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Kerry Walsh	Building Officials Institute of New Zealand
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Cover image credit: Structural light adobe house build in progress, Te Tai-o-Aorere (Tasman District), by Verena Maeder of Solid Earth Adobe Buildings.

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AMENDMENTS

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New Zealand Standard

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Superseding NZS 4297:2020

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REFERENCED DOCUMENTS

Reference is made in this document to the following:

New Zealand standards

NZS 1170:- - - -	Structural design actions
Part 5:2004	Earthquake actions – New Zealand
NZS 3101:2006	Concrete structures standard
NZS 3109:1997	Concrete construction
NZS 3602:2003	Timber and wood-based products for use in building
NZS 3604:2011	Timber-framed buildings
NZS 4210:2001	Masonry construction: Materials and workmanship
NZS 4230:2004	Design of reinforced concrete masonry structures
NZS 4297:2020	Engineering design of earth buildings
NZS 4298:2020	Earth building materials and construction
NZS 4299:2020	Earth buildings not requiring specific engineering design
NZS 7601:1978	Specification for polyethylene pipe (Type 3) for cold water services

Joint Australian/New Zealand standards

AS/NZS 1530:- - - -	Methods for fire tests on building materials, components and structures
Part 3:1999	Simultaneous determination of ignitability, flame propagation, heat release and smoke release
AS/NZS 1170:- - - -	Structural design actions
Part 0:2002	General principles
Part 1:2002	Permanent, imposed and other actions
Part 2:2021	Wind actions
Part 3:2003	Snow and ice actions
AS/NZS 1554: - - - -	Structural steel welding
Part 3:2014	Welding of reinforcing steel
AS/NZS 2053:- - - -	Conduits and fittings for electrical installations
Part 1:2001	(Reconfirmed 2016) General requirements
AS/NZS 4671:2019	Steel reinforcing materials

Australian standards

AS 1530:- - - -	Methods for fire tests on building materials, components and structures
Part 4:1975	Fire-resistance tests for elements of construction
AS 3700:2018	Masonry structures

British standard

BS EN ISO 10319:2015	Geosynthetics. Wide-width tensile test

Other publications

Acceptable Solutions and Verification Methods for New Zealand Building Code Clause B1 Structure; Clause B2 Durability, Ministry of Business, Innovation and Employment, 2019.

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Oliver, D and Whybird, D. Commercial Engineered Aggregate Construction, Proceedings of Economics in Building Conference, Brisbane, Australia, September 1991.

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Walker, R and Morris, H. 'Development of New Performance Based Standards for Earth Buildings'. *Australasian Structural Engineering Conference, Auckland 1998,* Proceedings Vol 1 pp 477-484.

Yttrup, P. 'Strength of Earth Masonry (Adobe) Walls Subjected to Lateral Wind Forces', Proceedings, 7th International Brick Masonry Conference, Melbourne, February 1985.

New Zealand legislation

Building Act 2004

Chartered Professional Engineers of New Zealand Act 2002

New Zealand Building Code (NZBC)

LATEST REVISIONS

The users of this standard should ensure that their copies of the above-mentioned New Zealand standards are the latest revisions. Amendments to referenced New Zealand and joint Australian/New Zealand standards can be found on www.standards.govt.nz.

REVIEW OF STANDARDS

Suggestions for improvement of this standard will be welcomed. They should be sent to the National Manager, Standards New Zealand, PO Box 1473, Wellington 6140.

FOREWORD

The previous editions of this suite of three standards, NZS 4297, NZS 4298, and NZS 4299, first published in 1998 and updated in 2020, have been a core resource for building consent authorities determining compliance with the New Zealand Building Code (NZBC) and have given guidance to designers, builders, owner-builders, and others involved in the construction of successful earth walled buildings in New Zealand, and elsewhere around the world. There has been no failure reported to date of any earth building built in accordance with this suite of standards.

Earth walled construction continues to be relevant at a time when the sustainability and decarbonisation of the built environment is under scrutiny. Earth materials are minimally processed, have low toxicity, and are available locally. These standards will encourage and enable the uptake of local earth materials with very low embodied energy within a decarbonising building industry.

The revised standards continue to be a core resource and reflect advances in earth building practice, research, changes in referenced standards, and changes in building legislation (the Building Act 2004 and the NZBC). They have been prepared to support users in demonstrating compliance with NZBC clauses B1 Structure, B2 Durability, C1–C6 Protection from fire, E2 External moisture, E3 Internal moisture, and H1 Energy efficiency. Commentary clauses are provided throughout to explain methodologies and provide additional information.

Low-density earth building materials, which provide improved thermal and seismic performance, are included in the revised standards, along with the more traditional, dense earth materials. Acceptable Solution E2/AS2 third edition amendments 4 and 5 to the 1998 standards are now incorporated in these standards.

NZS 4297, *Engineering design of earth buildings* is intended for use by structural engineers. Many of the structural design principles are chosen to be similar to those for reinforced masonry and reinforced concrete, and it is assumed that users of this standard will have a knowledge of design in these materials. However, earth has unique characteristics and needs to be considered apart from other forms of masonry.

NZS 4299, *Earth buildings not requiring specific engineering design* is primarily aimed at regular typical house configurations and includes careful expert consideration of the required detailing. Buildings that need engineering consideration to NZS 4297 because they are marginally outside the scope of NZS 4299 will need to include consideration for plan eccentricity, wall irregularity, structural continuity, and stiffness compatibility of load-carrying elements. The structure should be modified as necessary but maximise the use of the typical NZS 4299 details. Where there are unusual types of loads, or major changes to NZS 4299 type building form, engineers need a comprehensive understanding of earth materials and significant earth building design experience.

NZS 4298, *Materials and construction for earth buildings* sets out requirements for the use of unfired earth in the form of adobe, cob, pressed earth brick, rammed earth, and poured earth. It applies to buildings that are designed in accordance with NZS 4297 or NZS 4299.

Commentary to this standard takes heed of the long history of successful earth building worldwide. It is necessary to demonstrate that earth materials used (with or without admixtures) produce results that meet at least the minimum standards of strength and durability. Tests and the required results are detailed so that assurance can be given that the earth building material will meet NZBC requirements.

NZS 4299 is the earth building equivalent of NZS 3604, *Timber-framed buildings* but with its coverage limited to foundations, floor slabs, and walls including internal earth brick veneers. This revision covers single-storey reinforced earth walled buildings only. Two-storey buildings, unreinforced earth walled buildings, and other more ambitious structures are not included and require specific engineering design. Durability and weathertightness are covered by a methodology that relates required durability test results to the wind-driven rain exposure of any particular building site.

The revised edition of NZS 4299 includes additional and informative appendices intended to give guidance on the placement and finishing of straw bales and light earth method (LEM) material within specifically designed timber walls as additional substrates for the earth and lime plasters that are also now covered by this standard. The use of some unpublished work and the assistance of various practitioners from New Zealand and overseas while developing these appendices are acknowledged.

The materials covered by NZS 4297, NZS 4298, and NZS 4299 have been expanded to cover a variety of earth building techniques with material densities that range between dense rammed earth materials at 2200 kg/m^3 down to straw bales at 90 kg/m^3. The range of density of materials, as well as the inclusion of a section on internal veneers of earth bricks, gives designers a wide range of options for selecting materials either for thermal mass or insulation, or somewhere in between.

The inclusion of many drawings of construction details that have been proven in the New Zealand setting is intended to help builders in earth achieve durable, weathertight, and successful buildings. This will encourage the uptake of local earth materials with very low embodied energy within a decarbonising building industry.

Completion of this standard has been undertaken by a partnership between Standards New Zealand and the Earth Building Association of New Zealand (EBANZ). The role of all members of the standards development committee (a committee that includes some members and the chair of the 1998 committee), their nominating organisations, Standards New Zealand, and EBANZ in the success of this collaborative process is acknowledged. Thanks go to EBANZ for the research and fundraising that enabled this project to progress, to Martin Ulenberg for work on the diagrams, and to all those from within New Zealand and overseas who offered support or made donations of time or money for this project, including Te Kāhui Whaihanga | New Zealand Institute of Architects. Particular thanks are given to the Development Lead, Ian Brewer, for all his administrative and editing work.

The 2024 amendments have been carried out by the reconvened standards committee in conjunction with MBIE to make relevant parts of this standard suitable for consideration as references within Acceptable Solutions and Verification Methods for selected clauses of the NZBC, to amend some technical points in light of new information, and to correct some typographical errors.

Unreinforced earth buildings are removed from the scope of NZS 4297 as they are vulnerable to seismic loads and shaking where heavy bricks or components can fall on people.

OUTCOME STATEMENT

NZS 4297 is intended mainly for use by professional structural engineers. NZS 4297 provides designers and engineers with a cost-effective means of assessing the design of structures that incorporate unfired earth materials.

It is intended that NZS 4297 will be considered for referencing in Acceptable Solutions and Verification Methods that demonstrate compliance with the NZBC so that it will provide designers, building control officers, and builders with a clear methodology for substantiating building consent and code compliance certificate applications.

NZS 4297 needs to be read alongside NZS 4298 and NZS 4299 for practical guidance on materials, testing of those materials, and how to use those materials when constructing earth buildings.

New Zealand Standard

Engineering design of earth buildings

1 GENERAL

1.1 Objective

The objective of this standard is to provide for the structural and durability design of earth buildings. The standard is intended to be approved as a means of compliance with clauses B1 and B2 of the New Zealand Building Code (NZBC).

C1.1
NZS 4299 provides state-of-the-art construction details for earth building construction and an engineer should take account of this document when undertaking a design.

1.2 Application

1.2.1

This standard is intended to be used by persons who, on the basis of experience and qualification, are competent to design structural elements of the building under consideration to safely resist the design actions likely to be imposed on it.

An engineer with relevant experience and skills in structural engineering shall be responsible for the interpretation of the requirements of this standard for the earth building structural design. Refer to Verification Method B1/VM1 Paragraph 1.0.3(e), which states that a structural engineer who is chartered under the Chartered Professional Engineers of New Zealand Act 2002 would satisfy this requirement.

1.3 Scope

1.3.1

The scope of this standard is limited to reinforced earth construction with unfired earth wall building materials defined herein as adobe, pressed brick, cob, poured earth, in-situ adobe, or rammed earth and which contain clay and silt and which largely rely on the clay particles present to achieve satisfactory performance with or without chemical stabilisation, including cement. Earth building materials to which this standard applies shall comply with NZS 4298.

The dry density of earth materials shall be from 800 kg/m^3 to 2200 kg/m^3.

C1.3.1
Unreinforced earth construction is not within the scope of this standard.

1.3.2

Earth construction in accordance with this standard shall not exceed 6.0 m in height from the top of the foundation to the top of the earth wall.

Building layout above an earth walled ground floor shall be limited to a timber first floor, timber walled second storey up to 4.0 m high, and a light roof.

The maximum height of all earth walls shall be in accordance with 2.6.7.

C1.3.2
See Figure 1.1 for the height limitations for building layout above an earth walled ground floor.

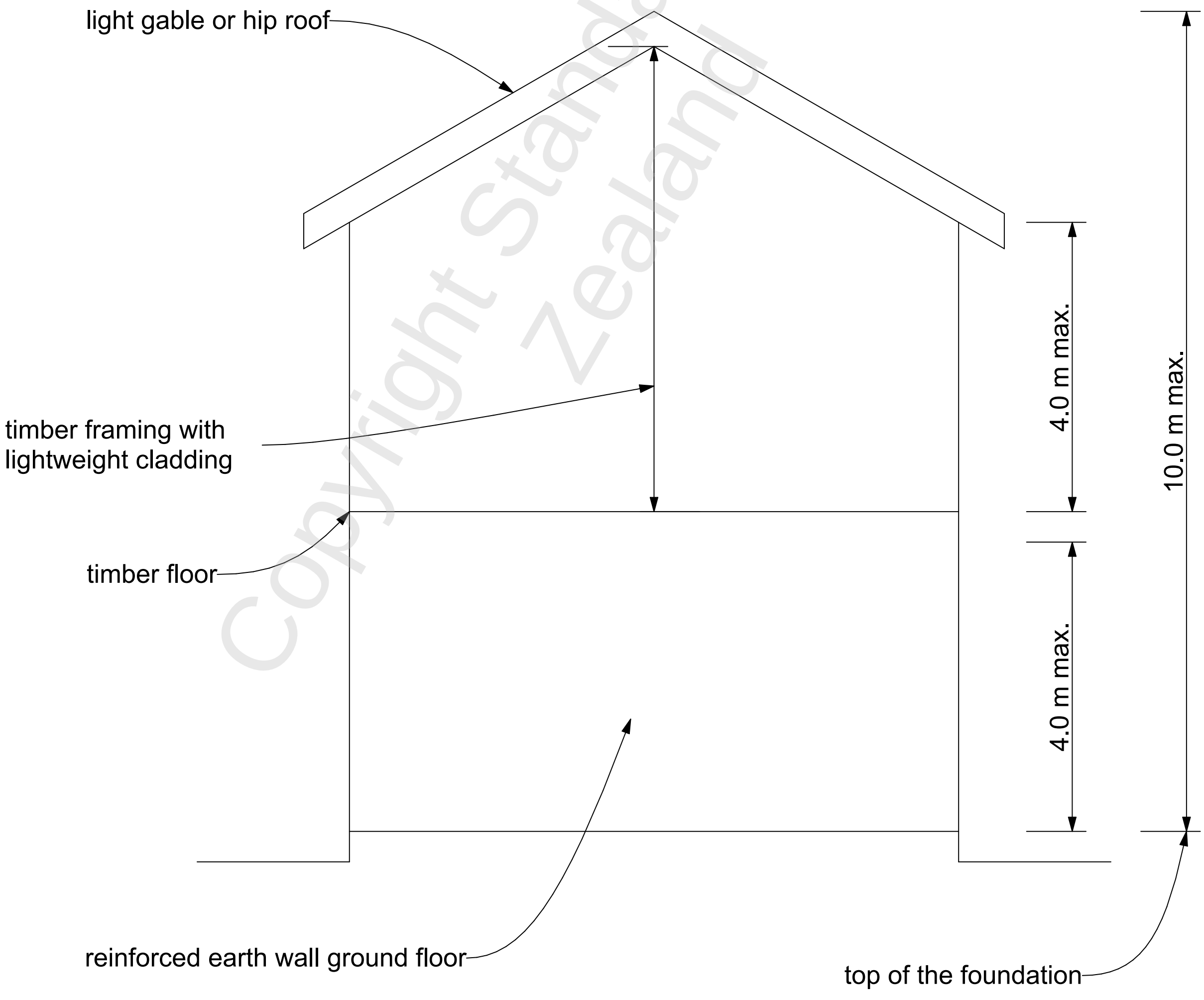

Figure 1.1 – Height limitations for building layout above an earth walled ground floor

1.3.3

This standard applies to earth wall items including house and building walls, boundary fences, outbuildings, isolated walls, footings, fireplaces, and any other items that could be subject to engineering design. This standard also covers components of any of the foregoing. Retaining walls are excluded from this standard.

C1.3.3

Design using procedures or material properties not described in this standard may be carried out when it can be shown by one of the following methods that the elements so designed have adequate performance at the serviceability limit state and at the ultimate limit state:

(a) A special study;

(b) Experimental verification;

(c) Rational design based on accepted engineering principles; or

(d) Verified service history.

Aspects of designs which rely on any of (a) to (d) above are outside the scope of this standard as a means of compliance with the NZBC and will be treated as alternative solutions.

The purpose of this clause is to acknowledge new design practices and the use of newly developed material properties that may go further than this standard permits, provided the acceptability of such methods or approaches can be clearly demonstrated by way of the options listed.

Building consent authorities will expect alternative design methods, material properties, and structural systems to be supported by one or more thorough experimental studies or demonstrated service history.

Demonstrating compliance of alternative solutions with the NZBC will be required under the legislation that governs the issuing of building consents.

Buildings in extra-high wind speed zones can be structurally designed but will be out of scope in terms of durability and erosion so these areas will require specialist alternative design.

Cement as a stabiliser can contribute substantially to strength in mixtures with a high proportion of sand. Where strength is almost entirely reliant on cement or another stabiliser, the masonry standard or the standard appropriate to that material should be used.

1.3.4

This standard applies to New Zealand and its offshore islands.

1.4 Interpretation

1.4.1

For the purposes of this standard, the word 'shall' refers to practices that are mandatory for compliance with this standard, while the word 'should' indicates a recommended practice.

Cross references to other clauses or clause subdivisions within this standard quote the number only.

C1.4.1(a)
An example: '... as required by 3.3.2.3(d) for shored construction'.

The full titles of referenced documents cited in this standard are listed immediately before the foreword.

Clauses prefixed by 'C' and printed in italic type are comments, explanations, summaries of technical background, recommended practice, or suggested approaches that satisfy the intent of the standard. Corresponding mandatory clauses are not always present. They are not to be taken as the only or complete interpretation of the corresponding clause nor should they be used for determining in any way the mandatory requirements of compliance within this standard. The standard can be complied with if the comment is ignored.

C1.4.1(b)
There is a need for background comment and explanation on topics other than those within mandatory clauses. This is to enhance the relatively small pool of earth building information and experience in New Zealand. Accordingly, the unusual format of having commentary clauses that have no corresponding mandatory clause has been adopted.

Dimensions, when used to describe timber sizes, refer to nominal or call dimensions. Actual dimensions shall be used for the purposes of calculation.

Provisions in this standard that are in non-specific or in unquantified terms (such as where provisions are required to be appropriate, adequate, suitable, relevant, satisfactory, acceptable, applicable, or the like and the standard does not describe how to achieve this) are outside the scope of this standard as a means of compliance with the NZBC and shall be treated as alternative solutions.

1.5 Earthquake hazard factor

The earthquake hazard factor, *Z*, shall be determined in accordance with NZS 1170.5.

1.6 Construction monitoring

Construction monitoring shall be carried out in accordance with clause 1.5 of NZS 4298.

1.7 Definitions

For the purposes of this standard, the following definitions shall apply:

Adobe (adobe brick)	An air-dried brick made from a puddled earth mix cast in a mould and which contains a mixture of clay, sand, silt, and aggregate. Sometimes contains a small proportion of straw or a stabiliser. Also known as mud-brick
Bodkin	A tie bar used to tie horizontal mesh reinforcing to vertical bar reinforcing at corners
Bond, overlapping	The bond when the units of each earth brick course overlap the units in the preceding course by between 25% and 75% of the length of the units
Bracing	Any method employed to provide lateral support to a building
Brick	A discrete unit of earth masonry made from earth materials, made by casting or pressing into a mould, and air dried
Characteristic strength	An estimate of the lower 5% value determined with 75% confidence from tests on a representative sample of full-size specimens
Characteristic unconfined compressive strength	The characteristic strength determined from compressive strength tests to which an aspect ratio correction factor has been applied
Clay	A fine-grained, natural, inorganic soil composed primarily of hydrous aluminium silicates with grain sizes less than 0.002 mm
Cob	A method of earth construction that involves placing a stiff mix of moist, unstabilised clay, silt, sand, gravel, and straw or other fibres directly into place in walls without the use of formwork or mortar
Cold joint	In rammed-earth and poured-earth construction, the joint that occurs when construction has been interrupted long enough for some degree of drying or curing to take place before fresh material is placed
Column	Isolated – An isolated, reinforced, vertical loadbearing member having a cross section with a ratio of depth to breadth of a value lying between 0.33 and 3 In a wall – A reinforced, vertical loadbearing member having a cross section with a ratio of wall width to wall length of a value lying between 0.70 and 4

Compressive strength	A physical property of a material that indicates its ability to withstand compressive forces, usually expressed in kPa or MPa
Control joint	A joint necessary to allow an earth wall to expand and contract or otherwise move
Curing	The action of water acting over time in a stabilised earth mass causing the mass to be cemented together by the stabiliser
Damp-proof course	A durable waterproof material placed between materials as a protection against moisture movement. A waterproof layer that is a sheet or is painted on is referred to as a damp-proof membrane
Design engineer	A person who, on the basis of experience or qualifications, is competent to design structural elements of the building under consideration to safely resist the design loads or effects on the building
Design strength	The nominal strength of a member section multiplied by the appropriate strength reduction factor
Dimension	When used to describe earth brick units or types of construction, means the nominal dimensions. Actual dimensions shall be used for the purpose of calculation. For timber, where the standard specifies members, those sizes shall be read as the actual minimum dried sizes
Ductility	The ability of a material, structural component, or structure to deform or dissipate energy beyond its elastic limit – that is, into the post-elastic range
Durable	Resistant to wear and decay. ‘Durability’ has a corresponding meaning
Earth (for earth building)	Natural subsoil composed of clay plus varying percentages of silt, sand, and gravel that is unfired and is free of significant organic matter other than that allowed by NZS 4298 and with an air dry density from 800 kg/m^3 to 2200 kg/m^3 inclusive
Elastic response	The response range of a structure where the deformation is in direct proportion to the force applied (that is, the material, structural component, or structure obeys Hooke’s law)
External wall	An outer wall of a building

Finished ground level	The level of the ground against any part of a building after any backfilling, landscaping, and surface paving have been completed
Flexural tensile strength	Also known as 'modulus of rupture' or 'flexural strength'. The flexural strength of the material as measured in accordance with Appendix G of NZS 4298
Flue	An enclosed continuous horizontal or vertical space in an earth brick element formed by the cells of the units which make up that member
Footing	That portion of a foundation bearing on the ground. It may be spread out to provide an increase in bearing area or an increase in stability
Foundation	Those parts of a building transmitting and distributing loads to the ground through a footing
Gable	Outside wall between the planes of the roof and the line of the eaves
Ground level	See 'finished ground level'
Grout	A liquid mixture of cement, sand, and water, with or without small aggregate, used to fill cavities after bricks and reinforcing have been placed
Light earth	A mixture of straw or other natural fibres and clay slip with a dry density greater than 200 kg/m^3 and a maximum density less than 1200 kg/m^3 that is tamped to form an insulated wall between or around structural members and around wall openings, with a dry density from 200 kg/m^3 to 1200 kg/m^3. Also known as 'straw-clay', 'clay straw', 'light LEM', 'clay-fibre', 'straw light clay', 'light straw clay', or 'chip and slip'. Other natural fibres such as wood shavings or reeds may be incorporated or substituted. Low-density mineral aggregates such as pumice or vermiculite may also be included
Limit state	See 'serviceability limit state' and 'ultimate limit state'
Loadbearing	An element which provides resistance to loads other than those induced by the weight of the element itself
Low-density earth	Adobe or cob used structurally with a dry density from 800 kg/m^3 to 1400 kg/m^3. Includes structural light adobe (SLA) and structural light cob (SLC)
Mortar	The bedding material in which earth brick units are bedded

Nominal strength	The theoretical strength of a member section, using the section dimensions as detailed and the characteristic strengths of its component materials
Non-loadbearing wall	A wall other than a loadbearing wall
Overstrength	Overstrength is used in seismic design. This increased value takes into account factors that can contribute to strength such as higher than specified strengths of the steel and earth, strain hardening, and additional reinforcement placed for construction and otherwise unaccounted for in the calculations
Partition	A light timber wall which is used within the building
Perpend	The perpendicular joint between two bricks
Pier (also known as pilaster)	A member similar to a column except that it is bonded into a wall. The thickness of a pier includes the thickness of the associated wall
Post-elastic behaviour	The large deformations accompanying a small increase in force after the elastic limit has been reached
Poured earth	An earth building technique in which earth and water, with or without stabiliser, are poured into moulds in place on the wall being constructed. The moulds are removed when the earth is strong enough to maintain its shape
Pressed earth brick (or pressed brick)	An earth brick that is made in a mechanical press, either machine operated or hand operated
Rammed earth	Damp or moist earth, with or without stabiliser, that is tamped in place between temporary moveable formwork. Also known as 'pisé' or 'pisé de terre'
Rammed-earth wall panel	A section of rammed-earth wall being of full height of the finished section but of length that is built at one stage
Reinforced earth construction	Any earth structure into which reinforcing is so bedded and bonded that the two materials act together in resisting forces
Reinforcement	Any form of steel reinforcing rod, bar, or mesh that complies with the relevant requirements of AS/NZS 4671, or plastic or other material cited in this standard and capable of imparting tensile strength to the earth building material

Serviceability limit state	The state at which a structure becomes unfit for its intended use through deformation, vibratory response, degradation, or other operational inadequacy
Shrinkage	The decrease in volume of earth material or mortar caused by curing or the evaporation of water. Expressed as a percentage of linear dimension
Silt	Individual mineral particles in a soil that range in size from the upper limit of clay (0.002 mm) to the lower limit of fine sand (0.06 mm)
Soil	In this standard, refers to the natural, undisturbed ground that is adjacent to and underlies buildings and also refers to the source of raw materials for earth building construction. See 'earth'
Spacing	The distance at which members are spaced measured centre to centre
Stabilisation	The improvement of the performance of earth building material properties by the addition of materials which bind the earth particles. Stabilisation can increase the resistance of earth to moisture, reduce volume changes, or improve strength or durability
Stabiliser	A material which is used for stabilisation
Strength	See 'design strength', 'nominal strength', and 'overstrength'
Ultimate limit state	The state at which the strength or ductility capacity of the structure is exceeded and it cannot maintain equilibrium so becomes unstable
Wall	See 'external wall', 'non-loadbearing wall', and 'partition'
Wall thickness	Minimum thickness of wall remaining after any chasing, raking, or tooling of mortar joints but excluding the surface coating, if any

1.8 Abbreviations

The following abbreviations are used in this standard.

EBANZ	Earth Building Association of New Zealand
FRR	Fire-resistance rating
LEM	Light earth method
MBIE	Ministry of Business, Innovation and Employment

NZBC	New Zealand Building Code
NZSEE	New Zealand Society for Earthquake Engineering
SLA	Structural light adobe
SLC	Structural light cob

1.9 Notation

In this standard, symbols shall have the following meanings. Other symbols, or other meanings for symbols listed below, that are defined immediately adjacent to formulae or diagrams shall apply only to those formulae or diagrams. Use of these symbols is subject to the following:

(a) Where non-dimensional ratios are involved, both the numerator and denominator are expressed in consistent units; and

(b) Dimensional units used, expressions, or equations shall be consistent unless otherwise specified.

A_b = area of earth cross section

A_{de} = effective area of dispersion of the concentrated load in the member at mid-height

A_{ds} = bearing or dispersion area of the concentrated load

A_s = area of tensile reinforcement

A_{sv} = area of shear reinforcement

a_v = coefficient for assessing slenderness ratio

a_1 = distance from the end or edge of the wall or pier to the nearest end of the bearing area

d = depth of section in the direction of shear

d_b = bar diameter

E_e = modulus of elasticity of earth

E_s = modulus of elasticity of reinforcing steel

e = eccentricity of vertical force

f_d = compressive stress acting on a section under the design loading – N^*/A_b

f_e = compressive strength of earth wall construction

f_{ea} = adjusted compressive strength for multiple brick construction

f_{eb} = tensile flexural bond strength

f_{es} = shear strength of earth

f_{et} = flexural tensile strength of earth

f_n = total nominal shear stress

f_{sy} = lower yield strength of shear reinforcement

f_y = lower characteristic yield strength of reinforcement

f'_{uc} = unconfined compressive strength of sample

h = height of earth wall in metres above the plane being considered; or

= height of a member; or

= clear height of a member between horizontal lateral supports; or

= for a member without top horizontal support, the overall height from the bottom lateral support

jd = proportion of d, the distance from the extreme compression fibre to the centroid of the tension reinforcement

k = reduction factor for slenderness and eccentricity

k_b = concentrated bearing factor

k_m = multiple brick factor

k_v = shear factor

L = clear length of a wall between vertical lateral supports; or

= for a wall without a vertical support at its end or at a control joint, the length to that unsupported end or control joint; or

= clear length of the wall or pier

L_e = dispersion zone length

M_{ch} = design flexural strength of the wall

M_n = nominal flexural strength of a section

M^* = design bending moment acting on the cross section of a member at the ultimate limit state determined from loads complying with AS/NZS 1170 and NZS 1170.5

M^*_{dh} = design horizontal flexural bending moment on a wall

N_o = nominal compressive strength of an earth cross section short enough for slenderness effects to have no influence

N^* = design axial load at the ultimate limit state determined from AS/NZS 1170 and NZS 1170.5

S^* = design action at the ultimate limit state

S_n = nominal strength at the ultimate limit state for the relevant action of moment, axial load, shear, and torsion

S_p = structural performance factor

S_r = slenderness ratio

s = spacing of shear reinforcement measured perpendicular to shear force

t = thickness or depth of wall perpendicular to the axis under consideration

t_w = overall dimensions thickness of a wall or isolated pier, taking into account any joint raking that is deeper than 3 mm

V_n = nominal shear strength of a section

V^* = design shear force acting on the cross section of a member at ultimate limit state determined from AS/NZS 1170 and NZS 1170.5

Z = earthquake hazard factor

Z_u = the lateral section modulus of the earth wall based on the gross cross section

δ = coefficient of variation

μ = structural ductility factor, as defined in NZS 1170.5

ρ = density

ϕ = capacity reduction factor

2 LIMIT STATE DESIGN REQUIREMENTS AND MATERIAL PROPERTIES

2.1 Notation

E_e = modulus of elasticity of earth

E_s = modulus of elasticity of reinforcing steel

f_e = compressive strength of earth wall construction

f_{ea} = adjusted compressive strength for multiple brick construction

f_{eb} = tensile flexural bond strength

f_{es} = shear strength of earth

f_{et} = flexural tensile strength of earth

f_n = total nominal shear stress

f_y = lower characteristic yield strength of reinforcement

f'_{uc} = unconfined compressive strength of sample

h = height of earth wall above the plane being considered

k_m = multiple brick factor

L = clear length of a wall between vertical lateral supports

S_n = nominal strength at the ultimate limit state for the relevant action of moment, axial load, shear, and torsion

S_p = structural performance factor

S_r = slenderness ratio

S^* = design action at the ultimate limit state

Z = earthquake hazard factor

δ = coefficient of variation

μ = structural ductility factor, as defined in NZS 1170.5

ρ = density

ϕ = capacity reduction factor

2.2 Scope

This section contains the general requirements for all types of earth buildings of brick type or solid homogeneous structure.

2.3 Design objectives

In addition to meeting the specific engineering design requirements of this section, the design engineer shall take account of the shape and dimensions of walls and construction practices including methods of positioning reinforcement and the placing and compacting of materials, mortar, or grout.

C2.3

Design and detailing should be such as to promote the following:

(a) Walls of consistent quality;

(b) Development of bond of grout to both reinforcement and bricks (where applicable);

(c) Control of shrinkage and settlement of earth and, where used, mortar and grout;

(d) Avoidance of corrosion of reinforcement;

(e) Minimising of adverse weathering effects of types which adversely affect structural adequacy and serviceability.

2.4 Earth building materials

2.4.1 General

Earth building materials shall comply with NZS 4298.

2.4.2 Standard grade earth construction

2.4.2.1 Earth materials compliance

Earth materials for standard grade earth construction shall comply with section 2 of NZS 4298.

2.4.2.2 Limitations

Standard grade earth construction shall be carried out only within the following limitations:

(a) The floor live load on suspended floors shall not exceed 1.5 kPa or 2.0 kPa on domestic balconies as provided for in AS/NZS 1170. Suspended floors shall have a dead load of less than 0.9 kPa;

(b) Buildings shall be Importance Levels 1 and 2 as defined in clause 3.2 of AS/NZS 1170.0;

(c) The total height of the earth wall, including any gable end, from the foundation top surface adjoining shall not exceed 6.0 m.

2.4.2.3 Design strengths of standard grade earth wall

Strengths used in design shall be as given in Table 2.1.

Table 2.1 – Strengths (MPa) to be used for design of standard grade earth wall construction

Compressive strength (flexural, direct compression or bearing) (a) for earth wall density from 1400 kg/m³ to 2200 kg/m³ (b) for earth wall density from 800 kg/m³ up to 1400 kg/m³	 $f_e = 0.5$ $f_e = 0.35$
Maximum total nominal shear stress	$f_n = 0.09$
Shear strength of earth for wind loading and for seismic load with elastic response	$f_{es} = 0.08$
Shear strength of earth for nominally ductile (μ = 1.25) seismic loading	$f_{es} = 0.0$
Shear strength of steel-reinforced earth	$f_{es} = 0.35$
Tensile flexural bond strength of adobe and unstabilised brick masonry	$f_{eb} = 0.015$
Flexural tensile strength of pressed earth brick and cement/lime mortar	$f_{et} = 0.025$

C2.4.2.3

A wide variety of bond strengths have been encountered by earth building practitioners. Unstabilised earth brick construction has been found to have considerable bond strength, and values of 50 kPa have been measured, but zero bond strength has also been encountered. Up to 260 kPa bond has been measured in cement stabilised in situ adobe construction. Up to 890 kPa flexural tensile strength has been tested for cement stabilised pressed brick. However, little is known about the as-built flexural strength of rammed-earth panels and how this is affected by cold joints and irregularities. In view of all these uncertainties and variabilities, designers may only use a higher tensile flexural bond strength if this strength is substantiated by pre-testing.

The in-wall strengths of Table 2.1 are less than the strength test results obtained in the laboratory. Modifications for aspect ratio, characteristic strength, and mortar effects as outlined in this standard all bring about reductions.

Where higher-strength materials are used, the more detailed methods of AS 3700 or NZS 4230 may be used. This could be the case where materials have similar strengths to fired clay or concrete masonry, or higher strengths than are available with this standard. Designs so based are outside the scope of this standard.

The shear value f_{es} depends on compressive load and, unless this is known, is assigned as zero.

2.4.2.4 Multiple brick factor for out-of-plane wall strength

Where an earth wall panel is 10 or more bricks long, the compressive strength shall be increased by the multiple brick factor k_m. The adjusted compressive strength shall be used in establishing out-of-plane flexural strength.

$$f_{ea} = k_m f_e \quad \text{(Eq. 2.1)}$$

where:

$k_m = 1.15$

f_{ea} is the adjusted compressive strength

If the coefficient of variation (δ) is established as 0.35 or higher from the test results of 30 or more specimens, then k_m shall be taken as 1.3.

C2.4.2.4
The compressive strength f_e is based on statistical analysis. Where multiple bricks are working in parallel, the probability of one brick failing or causing significant strength loss is less. Weaker earth bricks have lower stiffness, allowing load sharing with stronger, stiffer bricks. Design strengths for materials with $\delta > 0.35$ are reduced significantly to allow for the material variation. Walls of these materials benefit the most from load sharing.

2.4.3 Special grade earth construction

2.4.3.1 Compressive and flexural strengths

The compressive strength f_e and the flexural tensile strength f_{et} shall be established using the test methods of the appendices of NZS 4298.

Where f_e is based on the testing of individual specimens rather than prisms with mortar joints, the following relationship between the unconfined compressive strength of the sample (f'_{uc}) and the wall strength (f_e) shall be taken as follows:

(a) Adobe, cob, poured or rammed earth $f_e = f'_{uc}$; and

(b) Pressed earth bricks $f_e = 0.5\, f'_{uc}$.

2.4.3.2 Brick compressive strength derived from flexural tensile strength

In the absence of compression tests, where testing for flexural tensile strength to Appendix G of NZS 4298 has been done, the compressive strength shall be calculated from the flexural tensile strength as follows:

(a) For earth wall density from 1400 kg/m^3 to 2200 kg/m^3 $\quad f_e = 3.0\, f_{et}$

(b) For earth wall density from 800 kg/m^3 up to 1400 kg/m^3 $\quad f_e = 1.3\, f_{et}$

C2.4.3.2
The formulae for compression strength derived from flexural tensile strength are based on conservative test results. Compression tests are likely to give higher f_e/f_{et} ratios.

2.4.3.3 Joint strength

Where the compressive strength is greater than 6 MPa, the joint strength shall be taken into account for earth brick walls. Such considerations are outside the scope of this standard.

2.4.3.4 Shear strength

The shear strength of earth, f_{es}, shall be given by the greater of:

$$f_{es} = 0.07\ f_e \qquad \text{(Eq. 2.2)}$$

or

$$f_{es} = (70 + 5\ h)\ \text{kPa} \qquad \text{(Eq. 2.3)}$$

where

h = height of earth wall above the plane being considered in metres.

2.4.3.5 Flexural tensile strength

In the absence of flexural tensile strength test results, but where testing for compressive strength in accordance with NZS 4298 has been carried out, the flexural tensile strength, (f_{et}), shall be taken as 0.10 f_e for earth building materials with a compressive strength less than 6 MPa. For materials with a strength of 6 MPa and above, the flexural tensile strength shall be determined by testing in accordance with NZS 4298.

2.4.3.6 Modulus of elasticity of earth

The modulus of elasticity, (E_e), for earth wall construction shall be taken as follows:

(a) For 800 $> \rho \leq 1400$ kg/m^3 $E_e = 50$ MPa;

(b) For 1400 $> \rho \leq 1800$ kg/m^3 $E_e = 200$ MPa; and

(c) For 1800 $> \rho \leq 2200$ kg/m^3 $E_e = 300$ MPa.

C2.4.3.6

The modulus of elasticity of cement stabilised earth varies depending on the type of earth and increases approximately linearly with strength. This formula will give a low average estimate for silty earths. An appropriate higher value should be used if a low value will give non-conservative results.

For silty or poorly graded materials, the modulus of elasticity ranges from 120 kPa to 3 GPa. For silty-sandy clays and poorly graded sands, the modulus of elasticity ranges from 3 GPa to 7 GPa. For silty sands and sandy clays, the modulus of elasticity lies nearer 7 GPa. For gravelly earths, the modulus of elasticity ranges from 7 GPa to 20 GPa.

Where the modulus of elasticity is critical, it should be established by test. Such testing should establish the internal modulus of elasticity. Internal measurement, by deformation measuring equipment attached to the specimen, will give substantially higher values than the modulus measured from external deformation measurements because of test system effects.

2.4.4 Serviceability

2.4.4.1 Deflection

Members subject to flexure shall be designed to have adequate stiffness to limit deflections or any deformations that could adversely affect the serviceability of the structure under service loads to the values required by AS/NZS 1170.

2.4.4.2 Minimum wall thickness for serviceability

Where the walls are not supporting nor attached to partitions or other construction likely to be damaged by large deflections, the minimum thickness shall be not less than the following:

(a) Simply supported: $h/18$ or $L/18$;

(b) One end continuous: $h/21$ or $L/21$;

(c) Both ends continuous: $h/22$ or $L/22$;

(d) Cantilever: $h/8$ or $L/8$,

where L is the clear length of a wall between vertical lateral supports.

A lesser thickness than that determined from the ratios above may be used where computation of deflections indicates that the lesser thickness may be used without adverse effects.

C2.4.4.2
The minimum thickness for structural considerations is given in 2.6.6.

These values are based on values given in AS 3700 and NZS 4230.

2.4.5 Elastic deflection

Computed deflections for seismic design under elastic response shall be limited to $h/150$.

2.4.6 Shrinkage and thermal control joints

Where control of cracking is required, the position of control joints shall be as detailed in section 11 of NZS 4299 and shall be detailed in the drawings and specifications.

2.4.7 Fire resistance

See section 4.

2.4.8 Water penetration

The structure shall be detailed such that the effects of water and moisture penetration do not affect the durability of the structure or its contents. Such detailing is outside the scope of this standard.

2.5 Strength

2.5.1 Required characteristic strength

The required characteristic unconfined compressive strength of wall units or rammed-earth samples shall be stated on the drawings and in the specifications.

Standard grade earth materials are the minimum grade of earth materials to be used for construction complying with NZS 4299 or for specific designs in accordance with this standard utilising the design strengths of Table 2.1.

2.5.2 Testing

Testing shall be carried out in accordance with NZS 4298 for standard grade earth materials and for special grade earth materials.

The required testing includes both a testing regime for determining acceptable materials prior to construction commencing and quality control tests to be conducted during construction. See NZS 4298.

2.6 Ultimate limit state requirements

2.6.1 General requirements

The design strength of a member or cross section in terms of load, moment, shear, or stress shall be taken as the nominal strength, S_n, calculated in accordance with the requirements and assumptions of this standard, multiplied by a capacity reduction factor, ϕ.

2.6.2 Design strength

The design strength of a member or cross section shall be equal to or greater than the applied action, S^*, resulting from the design loads of AS/NZS 1170 and NZS 1170.5.

In general terms, 2.6.1 is expressed as:

$$S^* \leq \phi S_n \qquad \text{(Eq. 2.4)}$$

where S is replaced by the actions of moment, axial force, shear, or torsion as appropriate.

2.6.3 Capacity reduction factors

The capacity reduction factors shall be as follows:

(a) ϕ = 0.60 for axial compression and bearing;

(b) ϕ = 0.80 for flexure;

(c) ϕ = 0.70 for shear;

(d) ϕ = 0.70 for metal connections embedded in earth;

(e) ϕ = 0.60 for flexure determined using *Seismic assessment of existing buildings, section C8: Unreinforced masonry buildings* (MBIE and others, 2017, see Referenced documents).

C2.6.3
These values are similar to those for concrete masonry.

The seismic assessment of existing buildings method refers to the method of C8.8.5 Wall elements under face load of 'C8: Unreinforced masonry buildings' (MBIE and others, 2017).

2.6.4 Additional requirements for members designed for seismic loading

When the design moments, axial loads, or shear forces for a section are derived from overstrengths of adjacent members or sections, in accordance with capacity design principles, a capacity reduction factor $\phi = 1$ shall be adopted.

2.6.5 Properties of reinforcing steel

The modulus of elasticity, E_s, of non-pre-stressed steel reinforcement shall be taken as 200 GPa.

Design shall not be based on a lower characteristic yield strength for reinforcing steel, f_y, in excess of 500 Mpa.

2.6.6 Minimum wall thickness

Loadbearing walls in buildings shall be a minimum of 250 mm thick. Internal earth brick veneers shall be a minimum of 120 mm thick.

C2.6.6
Walls could require additional insulation to meet thermal insulation requirements of NZBC clauses E3 and H1.

Refer to NZS 4299 for the assessment of thermal resistance values.

2.6.7 Maximum slenderness ratio

Maximum slenderness ratio, S_r, shall be as in accordance with Table 2.2.

Table 2.2 – Maximum slenderness ratio

Situation	Earthquake hazard factor (*Z*)	
	$Z \leq 0.2$	$Z > 0.2$
(a) Reinforced loadbearing wall and earth gable end walls	12	10
(b) Reinforced columns	8	6
(c) Reinforced non-loadbearing wall	14	12

C2.6.7
The values in Table 2.2 are recognised good practice based on data from overseas codes and experience in New Zealand.

2.6.8 Lateral restraint

Adequate lateral restraint shall be provided at wall tops by a diaphragm, bond beam, or other similar device. Lateral restraints shall be constructed from timber, steel, reinforced concrete or reinforced masonry, or a combination of these. They shall be designed to resist loads and actions imposed on them. Such design is outside the scope of this standard.

Bracing shall be distributed around the building as evenly as practicable to provide for:

(a) Out-of-plane effects;

(b) Torsion at each floor level and of the building as a whole.

> ***C2.6.8***
> *Designs should minimise the eccentricity of walls about the centre of mass of a building.*

2.7 Principles and requirements additional to 2.6 for members designed for seismic loading

2.7.1 Methods of design

2.7.1.1

To provide minimum resistance for the appropriate combination of gravity and seismic loads specified by AS/NZS 1170 and NZS 1170.5, design methods of sections 5, 6, and 7 of this standard, which are applicable to the structural systems, shall be used.

2.7.1.2

Nominally ductile and elastic response methods are applicable. Ductile methods shall not be used unless supported by a special study. Such special study is outside the scope of this standard.

2.7.1.3

In the case of nominally ductile and ductile design, all the shear strength of the wall shall be supplied by the shear reinforcing. That is, the shear strength contribution of the earth shall be neglected.

> ***C2.7.1.3***
> *Designers should note that the overall shear strength of the gross wall area is limited by the provisions of Table 2.1 and 2.7.1.3.*

2.7.1.4

Rammed-earth walls without horizontal reinforcing shall be designed using the elastic response method.

2.7.1.5

The interaction of all structural and non-structural elements that, due to seismic displacements, could affect the response of the structure or the performance of non-structural elements, shall be considered in the design of that structure.

2.7.1.6

Consequences of failure of elements that are not a part of the intended primary system for resisting seismic forces shall also be considered.

2.7.1.7

Floor and roof systems in buildings shall be designed to act as horizontal structural elements, where required, to transfer seismic forces to frames or structural walls.

2.7.1.8

Structural systems and design methods, other than those covered in this standard, may be used if it can be shown by analysis or experiment based on accepted engineering principles that adequate strength, stiffness, and ductility for the anticipated seismic movements have been provided. Designs so based are outside the scope of this standard.

C2.7.1.8
Post-and-beam construction is one such building system that is covered by this clause.

2.7.2 Structural ductility factor and structural performance factor

In the derivation of the lateral seismic loading to be considered with the appropriate factored gravity load, the structural ductility factor, μ, as defined in NZS 1170.5, shall be taken as 1.0 for unreinforced walls and elastically responding reinforced walls and 1.25 for reinforced walls designed for nominal ductility.

The structural performance factor, S_p, as defined in NZS 1170.5 shall be taken as equal to 0.9.

Where appropriate, effects of concurrency in two-way horizontal force resisting systems shall comply with requirements of NZS 3101.

2.7.3 Assumptions and methods of analysis

In determining the minimum strengths for members designed for the maximum effects of factored static loads determined by elastic analysis, or for effects derived from other analysis, as permitted by AS/NZS 1170 and NZS 1170.5, the capacity reduction factors specified in 2.6.3 shall be used.

Redistribution of the design moments obtained from elastic analyses shall not be allowed.

2.7.4 Material properties

Structural ductility factors shall be as in 7.4.1.1.

Earth shall be pre-tested to the requirements of NZS 4298 to demonstrate the strengths to be used in design if higher strengths than those given by 2.4.2.3 are to be used.

The grade of reinforcement used shall be only that specified, except that substitution of higher grades of reinforcement may be made, provided that there are no detrimental effects on structural performance.

C2.7.4

The presence of greater than allowed for reinforcement strength could cause an undesired change in the mode of failure at ultimate limit state. It could cause the condition imposed by 2.7.1.2 to be violated, promoting the possibility of brittle failure of earth in place of ductile yielding of steel.

2.7.5 Stiffness

2.7.5.1 Effects of cracking

Allowances shall be made for the effects of cracking on the stiffness of various structural members, where applicable, for the purpose of estimating periods of vibration and structural deformations, to comply with the requirements of AS/NZS 1170 and NZS 1170.5.

2.7.5.2 Effects of distortions

In the estimation of stiffness or deformations of shear walls and other deep members, allowance shall be made for shear distortions, and distortions of anchorages and foundations, where appropriate.

2.7.6 Structures with limited ductility

In structures with limited ductility, the system as a whole or the primary lateral load-resisting components are not considered to be capable of sustaining the inelastic displacements that are expected in fully ductile structures without significant loss of strength or reduction in energy-dissipating capacity.

2.7.7 Elastically responding structures

Structures that are expected to respond elastically to large earthquake motions, in accordance with 2.7.1, shall be designed to withstand loads derived assuming elastic response. They are exempt from the additional seismic requirements of all relevant sections of this standard, provided that the earthquake design load used is that specified by NZS 1170.5 for these types of structures. For such structures, strength design procedures in accordance with the general principles and requirements of the relevant sections of this standard shall be used.

2.7.8 Foundations

General design principles for concrete foundations shall comply with the requirements of sections 2 and 14 of NZS 3101.

2.8 Control joints and shrinkage

Control joints shall be included to take account of shrinkage. Detailing shall ensure that movement at control joints can take place while still maintaining structural integrity and watertightness. Cracking that does not affect structural integrity may be plastered. For more information on control joints, refer to NZS 4299 section 11.

C2.8

Detailing of the frames for doors and windows needs to take account of both the vertical and horizontal shrinkage of earth building materials. Limiting cracks to maintain integrity against insects is important but is not an NZBC requirement.

Unstabilised earth walls rely mainly on the presence of clay to maintain their integrity. The amount and type of clay present influences the amount of shrinkage that takes place as the walls or bricks dry out. While the presence of shrinkage cracks in individual bricks can sometimes be a feature of adobe construction, there is a need to limit cracks in completed walls to an acceptable size.

Cement stabilised walls or bricks generally have low clay content but there is still some shrinkage due to the cement and clay content.

Vertical shrinkage control joints should also be located with consideration for:

(a) Soil stability of site;

(b) Seismic zone;

(c) Overall structural integrity of the building; and

(d) The need to avoid multiple small panels adjacent to each other.

3 DESIGN ALLOWANCE FOR DURABILITY

3.1 General

Compliance with this section is necessary to satisfy the requirements of clause B2 of the NZBC to provide for a building life of not less than 50 years.

3.2 Earth materials

3.2.1 Structural design for reduction of wall thickness by erosion

Durability of external walls is related to weather exposure, and to wind-driven rain in particular.

An earth wall will be deemed to comply with the durability performance criteria of this standard if, provided that normal surface maintenance has been carried out, its average thickness has not decreased by more than 5% or by more than 30 mm at any point during the building's life.

Structural design shall be based on reduced wall thickness taking account of allowance for erosion, provided that normal surface maintenance has been carried out, so that its thickness has not decreased by more than 5% or by more than 30 mm at any point during the building's life.

The structural integrity of each wall panel shall be maintained through normal maintenance as required in subclause 2.6.2.6 of NZS 4299. No continuous defect shall be more than one-tenth of the wall thickness and it shall not exceed 300 mm in length and height. Total defects shall not exceed 2% of the total wall panel surface area.

Normal maintenance of earth building material shall include the repair of damage or deterioration of the wall surface, including any surface coating, and the removal of any source of moisture that is capable of causing localised elevation of earth wall moisture content. Such sources can include plumbing or roofing leaks, channelling of rainwater, bridging or other loss of integrity of the damp-proof course, vegetation, or build-up of ground levels. Repair of earth building material shall be carried out using the same material as that from which the earth wall is constructed and be applied in accordance with NZS 4298. Curing of repair mixtures containing lime or cement shall be carried out in accordance with NZS 4298. Surface coatings that are impervious to water vapour shall not be used.

C3.2.1

Earth walls are particularly susceptible to moisture, whether this is from rising damp, water ingress from the top, driving rain, water splashing, or moisture generated internally in a building. For this reason, it is important that any design considers the need to protect earth walls from excessive moisture. Care is to be taken with all weathering details, including flashings and eaves to protect wall tops. It is important that any applied coatings or surface finishes provide permeability to prevent moisture becoming trapped inside an earth wall.

A structure is durable if it withstands wear and deterioration throughout its intended life without the need for undue maintenance. Deterioration of earth walls depends on the severity of wind-driven rain, on the orientation of the wall, on the roof overhangs, on the weather resistance of the wall material, on surface coatings, on the surface finish, and on the degree of stabilisation of the material. Note that experience has shown that relying on historic performance to reduce roof overhang protection needs to be done with considerable care.

3.2.2 Erodibility index and associated roof overhangs

Walls shall be considered satisfactory in terms of 3.2.1 if the erodibility index of a sample (as determined in accordance with appendices K or L of NZS 4298) is less than or equal to the limiting erodibility index determined by these tests and used in conjunction with the minimum weather protection determined in accordance with clause 2.7 of NZS 4299.

The material tests in NZS 4298 appendices J, K, and L that relate to durability are predicated on the walls having the minimum weather protection prescribed in NZS 4299. Reliance on these tests without this weather protection is outside the scope of this standard.

C3.2.2

Minimum roof overhangs on areas outside the scope of NZS 4299 or else determined by specific engineering design, are expected to be equal to or more than the minimum roof overhangs in clause 2.7 of NZS 4299, unless a special study on the same earth materials in a similar weathering situation can provide evidence of adequate performance. Observation has shown that, in some instances, poor performance of some earth materials that are excessively exposed to the weather has taken several years to become apparent, so caution is required when reducing roof overhangs below those determined by using the tables and figures of NZS 4299.

3.3 Timber

Timber shall comply with the requirements of NZS 4299, subclause 2.1.8, or with the requirements of NZS 3602.

3.4 Concrete

Concrete shall comply with the requirements of NZS 4299, subclause 2.1.2, or with the requirements of NZS 3101, section 3.

4 DESIGN FOR FIRE RESISTANCE

4.1 Fire resistance of earth construction

The fire resistance rating of earth construction shall be taken as 120/120/120 for a minimum wall thickness of 250 mm unless proved greater by testing in accordance with AS/NZS 1530.3. This fire rating applies only to heavy earth walls – that is, those with a density equal to or greater than 1400 kg/m^3.

For earth walls with a density of less than 1400 kg/m^3, specific testing to AS/NZS 1530.3 shall be undertaken to ascertain fire resistance.

4.2 No penetrations

No penetrations shall be permitted through any fire-rated earth wall unless they have been tested to verify the required fire resistance.

4.3 Strength and stability during and after fire

As part of the structural design process of the building containing the earth fire wall, the wall shall be checked by specific engineering design for strength and stability during and after fire in compliance with AS/NZS 1170.

4.4 Fire resistance values

The fire resistance values depend on the required covers to reinforcement being present, and that no flammable fibres remain visible on the finished surface of the wall.

C4.4

CSIRO Australia Bulletin 5 (1995) gives further details on fire tests; AS 3700 gives further details on fire design.

The rating given in 4.1 is based on information given in CSIRO Bulletin 5, where a 250 mm thick adobe wall is given a 4-hour fire-resistance rating (FRR) in terms of AS 1530.4:1975. The test is reported in EBS Technical Record 490.

Earth wall construction is non-combustible.

In New Zealand, the major construction uptake for earth building is expected to be private home construction where, generally, no fire resistance is required, depending on the distance and angle of the building in relation to the relevant boundary. If required, a minimum FRR of 30 minutes is expected. Some construction can be for transient accommodation; in this case, the maximum FRR required would be 60 minutes, well below all the test results achieved to date.

Earth construction used in public buildings or large warehouses can require an FRR greater than 60 minutes and is subject to specific fire engineering design.

Earth materials do not rely on flammable fibres for strength when exposed to fire. Fire can weaken a wall against subsequent wind or earthquake loading. Fire can contribute to smoke generation from flammable fibres unless they are encapsulated with earth.

5 REINFORCEMENT – DETAILS, ANCHORAGE, AND DEVELOPMENT

5.1 Notation

d_b = bar diameter

f_y = lower characteristic yield strength of reinforcement

5.2 Scope

Provisions of section 5 shall apply to detailing of steel reinforcement, including spacing and cover, and design of anchorage, development, and splices.

5.3 General principles and requirements for members designed for seismic loading

5.3.1 Steel reinforcement

Reinforcing bars and welded steel wire mesh shall conform to AS/NZS 4671.

Reinforcement details shall be in accordance with clause 2.8 of NZS 4298.

Joint reinforcement, where permitted to be used by this standard, may be fabricated in a form of a lattice truss with two 4 mm diameter mild steel wires connected by a 2 mm diameter lattice welded to them and the whole assembly hot-dip galvanised after fabrication. A ‘fish bone’ or ladder cut from welded steel mesh reinforcing may be used.

C5.3.1
Other types of joint reinforcement which satisfy the requirements of this standard and NZS 4298 may be used.

5.3.2 Spacing of reinforcement

The clear distance between parallel reinforcing bars in a layer shall be not less than the nominal diameter of the bars, nor less than 25 mm.

The nominal maximum size of earth particles shall not be larger than three-quarters of the minimum clear spacing between the individual reinforcing bars or bundles.

5.3.3 Mechanical anchorage

Anchorage of reinforcing shall be one of:

(a) An anchorage in concrete, in accordance with NZS 3101;

(b) Either of:

(i) A maximum 6 mm bar standard hooked 300 mm around a minimum 12 mm bar for adobe

(ii) A maximum 10 mm bar for rammed earth and pressed brick hooked 300 mm around a minimum 12 mm bar;

(c) Anchorage to a timber block or plate such that the provisions of 5.3.4 are complied with and the full tensile strength of the reinforcing bar is able to be developed.

5.3.4 Adequate bearing strength

Earth material in contact with anchorages shall have adequate bearing strength in accordance with 7.4.8.

5.3.5 Splices in reinforcement

5.3.5.1 General

Splices of reinforcement shall be indicated on the design drawings or in specifications. Splices embedded in earth material (rather than in cement grout filled cores) shall be welded or mechanically joined in accordance with 5.3.5.4.

C5.3.5.1
Tests can be used to confirm that the ultimate strength of the bar is developed by lapped splices; however, such testing is outside the scope of this standard.

5.3.5.2 Welding of reinforcing bars

Except as provided herein, all welding of reinforcing bars shall conform to AS/NZS 1554.3.

5.3.5.3 Welding restrictions

Welds shall not be made closer than 10 d_b from bends. Hard drawn steel reinforcing shall not be welded.

C5.3.5.3
Welding of reinforcing bars is now much less common and requires high-quality supervision. This needs to be undertaken with caution.

5.3.5.4 Conditions

Welded splices or mechanical connections satisfying the following conditions shall be used:

(a) Lap-welded splices designed in accordance with NZS 3101;

(b) Full-strength welded splices in which the bars are butt-welded to develop in tension the breaking strength of the bar; or

(c) High-strength welded splices in which the bars are butt-welded to develop in tension 1.6 f_y or the breaking strength of the bar, whichever is smaller; or

(d) Mechanical connections, which are defined as a connection that relies on mechanical interlock with the bar deformations to develop the connection capacity. A high-strength mechanical connection shall develop in tension or compression, as required, not less than 1.6 f_y or the breaking strength of the bar, whichever is smaller. When tested in tension or compression as appropriate, the change of length at a stress of 0.7 f_y in the bar and measured over the full length of the connection system shall be not more than twice that of an equal length of unspliced bar.

5.3.5.5 Shear reinforcing anchorage

Shear reinforcing shall be anchored at ends by one of:

(a) Providing a 180° bend with a 300 mm return around another bar;

(b) Embedment in concrete or grout sufficient to develop the tensile strength of the reinforcement which has a bearing area to earth that complies with 7.4.8; or

(c) Anchorage to a timber block or plate in accordance with the requirements of 5.3.3(c).

> ***C5.3.5.5***
> *Care should be taken to ensure adequate anchorage for shear reinforcement.*
>
> *The method of (a) above is not recommended for horizontal shear reinforcing greater than 6 mm diameter.*
>
> *Mechanical anchorage may be used, but the design of such anchorages is outside the scope of this standard.*

5.3.6 Protection for reinforcement

The minimum cover of earth or grout, whichever is applicable, provided for steel reinforcing bars shall be as shown in 2.8.7 of NZS 4298.

5.3.7 Protection of exposed reinforcing bars and fittings

Exposed reinforcing bars, inserts, and plates intended for bonding with future extensions shall be protected from corrosion.

5.3.8 Covers required for fire protection

Where fire design requires a fire-protection covering greater than the earth protection specified in 2.8.7 of NZS 4298, such greater thickness shall be used.

5.3.9 Wall reinforcement

Wall reinforcement shall be in accordance with 7.4 and 7.5.

5.3.10 Deformed/undeformed reinforcement

In rammed earth, to minimise the risk of cracking, steel vertical bars shall be encased in round smooth plastic sleeves.

D12 and HD12 bar sleeves shall be a maximum 16 mm in internal diameter.

D16 and HD16 bar sleeves shall be a maximum 21 mm in internal diameter.

> ***C5.3.10***
> *Examples of plastic sleeves can be found in NZS 4298 and NZS 4299.*
>
> *Sleeves may be pipe or conduit, low-density alkathene or polyethylene in accordance with NZS 7601, or medium-density uPVC in accordance with AS/NZS 2053.1.*

6 FOUNDATIONS

6.1 Notation

μ = structural ductility factor

ϕ = capacity reduction factor

6.2 General principles and requirements

6.2.1 Foundation width

Foundations shall be of reinforced concrete the same width as the earth wall that it supports, or of concrete masonry, fired brick, or stone masonry, all solid-filled with reinforced concrete.

Reinforced concrete masonry shall be the same width, or wider than, the wall above, except that a 240 mm wide masonry footing may support a 300 mm wide earth wall. For walls wider than 300 mm, reinforced concrete footings shall be used and they shall be the full width of the wall above. The outside face of the foundation or upstand that supports the earth wall shall not project beyond the outside face of the earth wall until it is more than 50 mm below the level of the bottom of the earth wall.

C6.2.1(a)
The limitation on the foundation not projecting beyond the earth wall is to avoid water ponding where it could soak the earth wall base.

C6.2.1(b)
Foundations should be designed using the methods of the NZBC Verification Method B1/VM4.

C6.2.1(c)
Components such as concrete block, fired brick, or stone masonry to give a fair finish to the outer exposed above-ground face of the reinforced concrete foundation may be used. Such components, if structural, are included within the specific engineering design requirements of this standard.

6.3 Loads and reactions

6.3.1 Proportions, loads, and depths

Foundations shall be proportioned to resist the design loads and induced reactions, in accordance with the appropriate design requirements of this standard.

The base area of foundations shall be determined from external forces and moments resulting from factored loads, transmitted by the foundation to the soil, and soil strengths selected through principles of soil mechanics.

The foundation system of all structures shall be carried to depths such that adequate bearing is secured. Due allowance shall be made for the effects of a number of factors including, but not limited to, underlying ground conditions, soil type, presence of any expansive soils, slope of the land, depth to water table, seasonal changes of moisture, lateral movement of the ground, and movements of ground in unstable areas.

> ***C6.3.1***
> *Sensitive clay soils can be subject to significant volumetric change with seasonal changes in moisture content. This can lead to post-construction damage to concrete floors, particularly when construction is carried out in drought conditions. Exposed soils at the building site that exhibit cracking should be thoroughly wetted prior to the commencement of construction works.*

When combinations of deep and shallow foundations are necessary, differential settlement and torsional effects shall be considered in the design of foundation members and the provision of control joints.

Long-term settlements shall not impair the serviceability of the superstructure by cracking or movement.

6.3.2 Construction of foundations

Concrete shall be ordinary grade or higher, as defined in NZS 3109.

6.3.3 Moments in strip foundations

Reinforcement shall be provided to the top and bottom of strip foundations to resist design loads and shall be not less than 200 mm^2 of steel in total. Design shall be in accordance with NZS 3101.

6.3.4 Shear in strip foundations

Minimum shear reinforcement shall be provided and spaced no further apart than 600 mm centre to centre. Design shall be in accordance with NZS 3101.

6.3.5 Minimum foundation height above finished ground level

Where finished ground is a paved surface, the top of the foundation (that is, the base of the earth wall) shall be no less than 200 mm above the finished paved surface level.

The height of the foundation (that is, the base of the earth wall) shall be no less than 275 mm above finished ground where this is soil, loose gravel, or other unpaved surface.

> ***C6.3.5***
> *The purpose of this subclause is to prevent moisture damage to the base of earth walls. Compliance will require careful design consideration and plan detailing of the proposed finished ground types and heights at all points around the structure.*

6.3.6 Preparation of top surface of foundation

The top of the foundation under the earth walls shall be cleaned of any laitance, be roughened to 5 mm amplitude, and have two coats of bituminous sealer applied so as to form a water-impermeable layer.

6.4 Principles and requirements additional to 6.3 for foundations designed for seismic loading

The foundation design shall be in accordance with the provisions of this standard using the factored loading specified in AS/NZS 1170 and NZS 1170.5, as modified by this standard.

The foundation system shall maintain its ability to support the design gravity loads while maintaining the chosen earthquake energy dissipating mechanism in the structure.

All members shall comply with the additional principles and requirements for members designed for seismic loadings as set down in the relevant sections of this standard. However, flexural members not designed for ductile behaviour, which have an ideal strength not less than the greatest total seismic load that can be transmitted to them from the superstructure, need not comply with these requirements.

The foundations of shear walls shall have adequate overturning resistance to carry the overstrength flexural capacity as defined in 7.5.3.2 if $\mu > 1.0$.

7 STRUCTURAL WALLS AND COLUMNS – STRENGTH AND SERVICEABILITY

7.1 Notation

A_b = area of earth cross section

A_{de} = effective area of dispersion of the concentrated load in the member at mid height

A_{ds} = bearing or dispersion area of the concentrated load

A_s = area of tensile reinforcement

A_{sv} = area of shear reinforcement

a_v = coefficient for assessing slenderness ratio

a_1 = distance from the end of the wall or pier to the nearest end of the bearing area

d = depth of section in the direction of shear

e = eccentricity of vertical force

f_d = compressive stress acting on section under the design loading

f_e = compressive strength of earth wall construction

f_{es} = shear strength of earth

f_{et} = flexural tensile strength of earth

f_n = total nominal shear stress

f_{sy} = lower characteristic yield strength of shear reinforcement

f_y = lower characteristic yield strength of reinforcement

h = clear height of a member between horizontal lateral supports; or

= height of earth wall in metres above the plane being considered; or

= height of member for a member without top horizontal support, the overall height from the bottom lateral support

jd = proportion of d, the distance from the extreme compression fibre to the centroid of the tension reinforcement

k = reduction factor for slenderness and eccentricity

k_b = concentrated bearing factor

L = clear length of a wall between vertical lateral supports; or for a wall without a vertical support at its end or at a control joint, the length to that unsupported end or control joint; or

= clear length of the wall or pier

L_e = dispersion zone length

M_{ch} = design flexural strength of the wall

M_n = nominal flexural strength of a section

M^* = design bending moment acting on the cross section of a member, determined from loads complying with AS/NZS 1170 and NZS 1170.5

M^*_{dh} = design horizontal flexural bending moment on wall

N^* = design axial load at the ultimate limit state acting on a section determined from AS/NZS 1170 and NZS 1170.5

N_o = nominal compressive strength of the cross section, short enough for slenderness effects to have no influence

S_r = slenderness ratio spacing of shear reinforcement measured perpendicular to direction of shear force

t = thickness or depth of wall perpendicular to the principal axis under consideration

t_w = overall thickness of a wall or isolated pier, taking into account any joint raking which is deeper than 3 mm

V_n = nominal shear strength of the section (kN)

V^* = design shear force acting on the cross section of a member at ultimate limit state, assessed from AS/NZS 1170 and NZS 1170.5

Z_u = the lateral section modulus of the earth wall based on the gross cross section

δ = coefficient of variation

μ = structural ductility factor as defined in NZS 1170.5

ϕ = capacity reduction factor

7.2 General

Structures and structural members shall be designed to have design strengths at least equal to the required strengths calculated for the factored loads and applied forces in such combinations as are stipulated in AS/NZS 1170 and NZS 1170.5.

Structural members shall meet all requirements of this standard to ensure adequate performance at the serviceability limit state and at the ultimate limit state in such combinations as are stipulated in AS/NZS 1170 and NZS 1170.5.

7.3 Shear strength of bolts embedded in earth

7.3.1 Design strength

The design strength in shear of bolts embedded in earth shall be limited to the values given in Table 7.1 multiplied by the capacity reduction factor given by 2.6.3.

C7.3.1
The values of Table 7.1 are based on the methods of the Uniform Building Code (ICBO, 1994).

For pre-tested reinforced earth, the bolt nominal shear strength values may be established by computation, testing, or a combination of these two methods. Such methods are outside the scope of this standard.

Designers wishing to use higher values than in Table 7.1 are referred to the paper 'Commercial Engineered Aggregate Construction' by Oliver and Whybird. That document gives working loads for high-quality rammed earth.

See 7.3.6 for minimum bolt embedment requirement.

Table 7.1 – Nominal strength in shear of bolts in standard grade earth wall material

Diameter of bolt (mm)	Strength in shear (kN)
16	1.8
20	2.6
24	4.4
NOTE – The ϕ factor in accordance with 2.6.3 is to be applied to these strength values.	

7.3.2 Corrosion protection

Bolts shall be protected from corrosion in accordance with 2.8.7 of NZS 4298.

C7.3.2
In dry interior situations, the protected environment where the bolt is situated could provide sufficient corrosion protection for plain steel bolts.

7.3.3 Embedment

Bolts shall be embedded in earth mortar or sand and cement grout, in accordance with 7.3.6.

7.3.4 Loads on bolts

Loads on bolts shall take into account:

(a) Impact loads;

(b) Vibratory loads;

(c) Effect of volumetric changes due to shrinkage, creep, and temperature;

(d) All other loads.

7.3.5 Minimum edge distance

The minimum edge distance for bolts for standard grade earth construction measured to the centre line of the bolt shall not be less than the required embedment length except where:

(a) The load is reduced in the same proportion as the edge distance is reduced;

(b) The bolts are confined by reinforcing – then, the edge distance may be reduced by 50% but shall not be less than 100 mm.

7.3.6 Minimum embedment

The minimum bolt embedment shall be three-quarters of the wall thickness, with a minimum length of 200 mm. Where the wall is so thin that this is not possible, the nominal strength given by Table 7.1 shall be reduced by the ratio:

$$\frac{\textit{embedded bolt length (mm)}}{200} \quad \text{(Eq. 7.1)}$$

7.3.7 Embedded end

The embedded end of the bolt shall retain its normal head with a galvanised steel washer of minimum dimensions 50 mm × 50 mm × 3 mm or 55 mm diameter × 3 mm.

7.4 Flexure with or without axial load

7.4.1 Scope

7.4.1.1 General

The provisions of this section shall apply to the design of members for flexure with or without axial load.

The following values of the structural ductility factor μ shall apply for earthquake loading design to NZS 1170.5. For nominally ductility reinforced earth, μ shall be taken as 1.25. For elastically responding reinforced earth, μ shall be taken as 1.0.

7.4.1.2 Flexure

Walls and members subjected primarily to flexure shall be designed using methods for reinforced concrete and reinforced masonry design and similarly take account of shear.

7.4.1.3 Compression

A member that is subjected to a design axial load, N^*, in excess of 0.5 $f_e A_b$ shall be designed to have the total axial load carried by a core of timber, reinforced concrete, or steel.

When the design axial load on the member cross section, N^*, is less than 0.5 $f_e A_b$, then the member shall be designed as a wall or column.

Due account shall be taken of combined tension and wall flexure by the methods of this section and the assessment method in 2.6.2.

C7.4.1.3
Combined tension and wall flexure can occur in high wind load situations.

7.4.1.4 Uplift

Account shall be taken of uplift by the methods of this section and *Seismic assessment of existing buildings, section C8: Unreinforced masonry buildings*. Account shall be taken of the lowering of wall-bending strength due to the effective reduction of gravity axial loads because of wind uplift. The tensile strength of the wall material shall be assumed to be zero.

C7.4.1.4
The tensile strength of earth walls is close to zero so dead load of wall material is needed to resist uplift. Any connection to the top of the wall needs to be embedded either full depth to the foundation or to a depth such that the self-weight of the wall material attached to the connector is greater than the design uplift force. The effects of reduced axial compressive load on wall strength are considered in the methods of 'Seismic assessment of existing buildings, Section C8: Unreinforced masonry buildings' (see Referenced documents).

7.4.2 Structural end of an earth member

The structural end of an earth wall or column supporting vertical loads shall be the vertical surface in the member across which longitudinal shear cannot be transferred, and shall include:

(a) The actual end or vertical face of the member;

(b) A control joint in the member; and

(c) A vertical mortar joint in earth construction (other than perpend joints in normal overlapping bond).

7.4.3 General design assumptions

7.4.3.1

Strength design of members for flexure with or without axial loads shall be based on rational assumptions given in 7.4.3.2 and on satisfaction of applicable conditions of equilibrium, if reinforced.

7.4.3.2

The relationship between earth compressive stress distribution and earth strain shall be considered satisfied at an extreme fibre compression stress of f_e with a triangular or trapezoidal earth stress distribution.

C7.4.3.2

The relationship between earth wall compressive stress and strain may be assumed to be rectangular, trapezoidal, parabolic, or any other shape that results in prediction of strength in substantial agreement with results of comprehensive tests. Stress distributions other than triangular or trapezoidal are outside the scope of this standard.

Earth walls and columns are often designed on the basis of ultimate strength reinforced concrete theory where $M^* \leq \phi M_n$ and $M_n = A_s f_y\, jd$ where jd is a proportion of d, the distance from the extreme compression fibre to the centroid of the tension reinforcement.

7.4.4 Longitudinal reinforcement in flexural members

The failure mode in bending is to be a tension-initiated failure.

C7.4.4

It is recommended that the tensile strength of reinforcement should be no greater than 75% of the available flexural compressive strength of the section.

7.4.5 Compression reinforcement in members

Compression bar reinforcement shall not be relied upon to enhance the strength of earth members.

7.4.6 Distribution of flexural reinforcement

The flexural tension bar reinforcement shall be evenly distributed within the flexural tension zones of a member cross section.

C7.4.6

This clause prescribes the distribution of flexural reinforcement to control flexural cracking in flexural members.

7.4.7 Longitudinal reinforcement in columns

The diameter of longitudinal reinforcement used in a column shall not be greater than 16 mm.

The minimum longitudinal reinforcement for a column shall be 1 bar of 12 mm diameter.

7.4.8 Concentrated loads

7.4.8.1 General

Each concentrated compression load acting on an earth compression member shall be assumed to disperse through the earth construction as provided in 7.4.8.2, and each cross section within that zone of dispersion shall be designed to comply with 7.4.8.3.

7.4.8.2 Dispersion of a concentrated load through the earth construction

A concentrated load acting on a member shall be assumed to disperse through the earth construction at an angle of 45° (from the horizontal) from the perimeter of the bearing area of the load to the mid-depth of the member, but this dispersion is not to extend:

(a) Into the dispersion zone of an adjacent concentrated load on the member; or

(b) Beyond the structural end of the earth construction in the member as defined in 7.4.2.

C7.4.8.2
Special care is required in the detailing of the support of concentrated loads at or near the end of a wall. Figure 7.1 illustrates the principles of 7.4.8.2.

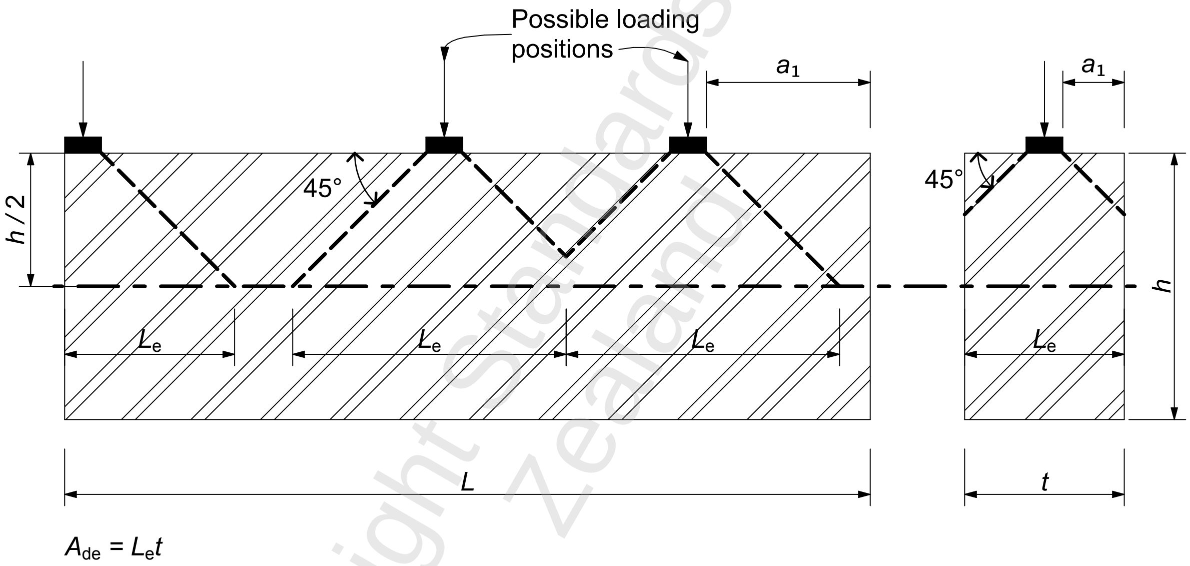

Figure 7.1 – Loading positions and effective areas of dispersion

7.4.8.3 Load capacity under a concentrated load

Where a member is of uniform and symmetrical cross section, it shall be designed to comply with 7.4.8, except that:

(a) The design axial load (N^*) acting on any given cross section shall include the design concentrated load, plus that portion of the other compressive forces that act on the cross-sectional area (A_b) under consideration;

(b) The design bending moment (M^*) acting on the same cross section under consideration shall include the bending moment, if any, from the design concentrated load, plus that portion of the bending moment from other loads and forces that act on that cross-sectional area (A_b);

(c) In addition, the member shall be designed to satisfy the following equation for each cross-section within the zone of dispersion of the concentrated load:

$$N^* \leq \phi k_b N_o \quad \text{(Eq. 7.2)}$$

where k_b is given by 7.4.8.4.

7.4.8.4 Concentrated bearing factor (k_b)

The value of the concentrated bearing factor (k_b) for use in subclause 7.4.8 shall be as follows:

(a) For cross sections at a distance greater than 0.25 *h* below the level of the bearing of the concentrated load on the member:

$$k_b = 1.00 \quad \text{(Eq. 7.3)}$$

(b) For cross sections at a distance within 0.25 *h* below the level of the bearing of the concentrated load on the member:

(i) Other than as in (ii) below (including ungrouted hollow unit brickwork), identical with Equation 7.3

(ii) In solid or cored unit brickwork or in grouted brickwork, whichever is less of Equation 7.4 or Equation 7.5, but k_b is not less than 1.0:

$$k_b = \frac{0.55\left(1 + 0.5\dfrac{a_1}{L}\right)}{\left(\dfrac{A_{ds}}{A_{de}}\right)} \quad \text{(Eq. 7.4)}$$

or

$$k_b = 1.50 + \frac{a_1}{L} \quad \text{(Eq. 7.5)}$$

where

A_{de} = effective area of dispersion of the concentrated load in the member at mid-height (= $L_e t$ [for L_e see Figure 7.1])

A_{ds} = bearing or dispersion area of the concentrated load at the design cross section under consideration

a_1 = distance from the end of the wall or pier to the nearest end of the bearing area

L = clear length of the wall or pier (see Figure 7.1)

NOTE – Where concentrated loads are applied in close proximity to each other, the value of A_{ds} and A_{de} shall be calculated in accordance with 7.4.8.2(a).

7.4.9 Principles and requirements additional to 7.4.2 for members not subject to seismic loading

7.4.9.1 Strength calculations

Columns shall be designed for the most unfavourable combination of design moment, (M^*), and design axial load, (N^*).

7.4.9.2 Composite columns

Where other material column sections are built into earth walls, or columns, the strength of the earth shall not be included in the calculation of the strength of the column section.

7.5 Shear

7.5.1 Scope

Provisions of 7.5 apply to design of earth walls for shear and torsion with flexure and with or without axial load. Design of earth walls for shear and torsion shall be in accordance with established principles for reinforced concrete, as set out in section 7 of NZS 3101, modified by the requirements of this section. Where no specific requirements are given in this section, the appropriate requirements of section 7 of NZS 3101 shall apply.

7.5.2 General principles and requirements

7.5.2.1 Design of reinforced earth shear walls

Design of wall cross sections subject to in-plane shear shall be based on:

$$V^* \leq \phi V_n \quad \text{(Eq. 7.6)}$$

where V^* is the design shear force at the section derived from factored load on the structure and V_n is the nominal shear strength of the section computed with the shear strength f_{es} from:

(a) Under elastic response or serviceability limit state conditions:

$V_n = f_{es} t\, d + A_{sv} f_{sy}\, d/s + k_v f_d\, t\, d$

but

$$V_n < 5 f_{et}\, d \quad \text{(Eq. 7.7)}$$

or

(b) Under nominal ductility seismic response:

$$V_n = A_{sv} f_{sy}\, \text{d/s} \quad \text{(Eq. 7.8)}$$

For in-plane shear walls with $L < h$, d shall be taken as 0.8 L, unless otherwise determined from a strain compatibility analysis.

No contribution from pretension shall be permitted for nominally ductile structures.

> ***C7.5.2.1***
> *Overturning or flexure can be critical even for low aspect ratio walls. Vertical reinforcement pretension will contribute to available shear strength under serviceability conditions and may be taken into account for elastically responding structures provided the pretension is maintained after shrinkage has taken place.*

For walls with $L \geq h$, d shall be taken as equal to L.

In determining shear strength, V_n, effects of axial tension, including tension from creep and shrinkage and from differential temperature, shall be considered wherever applicable.

7.5.2.2 Shear reinforcement details

Shear reinforcement shall consist of:

(a) Steel of either normal or high strength (either deformed or plain) except as provided by 5.3.10;

(b) Welded wire fabric within the plane of the member with wires cut to form ladders or fish bones; or

(c) Polypropylene biaxial or triaxial geogrid or similar. The quality control strength of the geogrid shall be determined in accordance with BS EN ISO 10319. The geogrid shall be cut into strips to form ladders of reinforcement.

C7.5.2.2.1
Other types of reinforcing may be used subject to rational engineering analysis but are outside the scope of this standard.

Bars or wires used as shear reinforcement shall be anchored at both ends according to 5.3.5.5 to develop the lower characteristic yield strength of reinforcement.

C7.5.2.2.2
Some practitioners also specify 'sensible minimums' horizontal reinforcing at every third course or at every 450 mm, whichever is least, whether the design calculations require them or not. More closely spaced horizontal reinforcing at 300 mm centres is generally preferred to horizontal reinforcing at 450 mm centres.

Shear reinforcement shall be evenly distributed through the height of the wall.

Polypropylene geogrids used as shear reinforcement shall be anchored to vertical reinforcing at each end of bracing walls with a 6 mm × 20 mm high-density polyethylene bodkin or 6 mm diameter minimum steel rod, threaded through the geogrid.

7.5.3 Principles and requirements additional to 7.5.2 for members designed for seismic shear actions

7.5.3.1 Shear strength

The provisions of 7.5.3 shall apply to members whose required nominal shear strength under seismic loading corresponds to a structural ductility factor μ of ≤ 1.25.

7.5.3.2 Shear force design

The design shear force in members subjected primarily to flexure shall be determined from considerations of static transverse forces on the member, with the flexural overstrength being developed at the most probable location of critical sections within the member or in adjacent members, together with the gravity load at the appropriate load factor.

7.5.3.3 Overstrength

Shear strength provided in nominal ductile walls shall have a suitable margin over required in-plane flexural strengths. The overstrength of the wall due to in-plane flexure shall be calculated to be a minimum of $1.25/\phi$.

C7.5.3.3

Where the nominally ductile wall is less than 1.4 m long, the influence on flexural overstrength should also be considered for an earth compression overstrength factor of a minimum of 4 unless the overstrength factor is determined from knowledge of the earth strength coefficient of variation. Such determination is outside the scope of this standard.

For nominal ductile wall design, a flexural mode of failure is required. This clause includes a factor of 1.25 $A_s f_y$ to account for steel overstrength.

In short walls, the length of the compression zone is significant in determining the moment capacity, and is significant in cases when allowance for the earth material overstrength should be made. In variable materials, the calculated value of characteristic strength can sometimes be well below the actual strength. Where the coefficient of variation is 0.2, the given overstrength is 4 based on (population average compressive strength)/(5 percentile of sample characteristic strength). For a coefficient of variation of 0.25, compressive overstrength is about 6, and for a coefficient of variation of 0.35, the overstrength could be 10 or higher.

7.5.3.4 Combined flexure and axial load

The design shear force in members subjected to combined flexure and axial load shall be determined from considerations of static forces on the member, with the worst likely combination of the maximum likely end moments, and where appropriate with flexural overstrength being developed at critical sections.

7.5.3.5 Nominal ductility

Where a structure is designed to perform with nominal ductility, then appropriate redistribution of shear loads shall be carried out.

7.5.3.6 Total nominal shear stress

Total nominal shear stress, f_n, shall not exceed the maximum grade-dependent values, f_{es}, listed in Table 2.1 and 2.4.3.4.

7.5.3.7 Shear strength provided by earth

7.5.3.7.1

In all potential plastic hinge regions of nominally ductile walls and columns with $\mu = 1.25$, the shear strength f_{es} shall be assumed to be zero for any seismic load combination.

7.5.3.7.2

For structures designed assuming elastic response, the shear strength of the earth may be used and horizontal reinforcement is not mandatory.

8 COLUMNS

8.1 General

The following are principles and requirements additional to 7.4.2 for members designed for seismic loading.

8.2 Notation

e = eccentricity of vertical force

t_w = overall thickness of a wall or isolated pier, taking into account any joint raking which is deeper than 3 mm

8.3 Strength calculations

Columns of earth shall not be used to provide main structure lateral load restraint unless they contain other material sections that can resist the whole of the lateral load.

Unreinforced columns are not permitted.

If e/t_w exceeds 0.2, then flexure about both axes shall be considered together. The combined action shall not put any part of the section into tension.

8.4 Column construction

Minimum column dimensions shall be 250 mm square if reinforced. The maximum slenderness ratio of a column shall be as stated in 2.6.7.

Columns shall be constructed so that any vertical flue shall have a minimum clear dimension of 60 mm and a minimum area of 9000 mm^2.

A column flue containing four bars shall have minimum clear flue dimensions of 150 mm × 150 mm.

Cover to the reinforcing steel shall be as required by 2.8.7 of NZS 4298.

Flues shall be filled with grout in accordance with NZS 4210.

8.5 Column durability

Exterior columns require the minimum weather protection as for walls as given by 2.7 of NZS 4299.

APPENDIX A – UNREINFORCED EARTH

(Informative)

A1 General

Unreinforced earth can include all forms of earth construction such as rammed earth, adobe, cob, poured earth, or pressed brick, whether stabilised or unstabilised.

CA1

There are a large number of historic buildings that are unreinforced, and this Appendix A provides preliminary guidance for assessing simple structures with unreinforced earth walls.

Unreinforced earth walls have been removed from the scope of NZS 4297 as they are mostly highly vulnerable to seismic loads and shaking where heavy bricks or components can fall on people with life-threatening consequences.

Unreinforced earth walls can only be feasibly used in seismic zones where there is a regular well-defined structural form and highly integrated load-resisting system that adequately confines the earth walls and components vertically and in every horizontal direction.

Suitability of structural form and integrity is beyond the scope of this Appendix A.

Although the methods in this appendix have been adopted from the unreinforced masonry section of AS 3700 and, strictly speaking, apply to brick constructions only, they are also conservatively specified for rammed earth as little is known about the tensile continuity between one rammed earth layer and the next.

A2 Basis of design

Each unreinforced earth member shall be designed to comply with A3 to A4.3, taking into account the strength of the material and the further provisions in A5 as applicable for the relevant type of member.

A3 Design for compressive forces and vertical bending

A3.1 General

Unreinforced earth members resisting compressive forces, with or without simultaneously acting bending moments, shall be designed to comply with A3.2. Design for concentrated loads on members shall comply with A3.3, and design for lightly loaded members under the action of transient out-of-plane forces shall comply with A4 or A4.3, as appropriate. The compressive strength depends upon the following factors:

(a) Slenderness;

(b) Effective eccentricity of loading at each end;

(c) Characteristic compressive strength of the earth;

(d) Cross-sectional area of the earth.

In a wall or isolated pier subject to compression and bending, the vertical and bending forces shall be combined at top and bottom of the member by regarding the vertical force as acting at statically equivalent effective eccentricities, *e*, at each end. In this calculation, the most unfavourable disposition of live loads shall be considered. The load combination shall be such that under the worst loading conditions, the equivalent effective eccentricity at any point does not exceed $t_w/6$.

> ***CA3.1***
> *Torsion due to earthquake forces should be minimised in seismic areas by having the combined centre of mass of all the walls in plan close to the centre of resistance.*

A3.2 Uniaxial bending and compression on uniform symmetrical members

A member shall be designed such that the following relationship is satisfied:

$N^* \leq k\phi N_o$ .... (Eq. A1.1)

where

$N_o = f_e A_b$ .... (Eq. A1.2)

Table A1 – Reduction factor (*k*) for slenderness and eccentricity

Slenderness ratio (S_r)	Reduction factor (*k*)				
	Eccentricity to thickness ratio (e/t_w)				
	≤ 0.05 (Note 5)	0.10	0.20	0.30	0.33
6	1.00	0.78	0.56	0.38	0.32
8	0.94	0.73	0.54	0.34	0.29
10	0.88	0.67	0.49	0.31	0.25
12	0.82	0.62	0.45	0.27	0.22
14	0.76	0.56	0.40	0.23	0.18
16	0.70	0.51	0.35	0.20	0.15
18	0.64	0.45	0.31	0.16	0.11

NOTE –

(1) Values above the dashed line correspond to failure by crushing.

(2) Values below the dashed line correspond to failure by lateral instability.

(3) Refer to A3.4 for the maximum allowable slenderness ratios.

(4) Linear interpolation may be used between the values given in this table.

(5) *e* = the larger eccentricity, at either top or bottom.

(6) The values of *k* for e/t_w = 0.05 are only applicable to columns.

C Table A1
Table A1 is a truncated version of Table 5.1 from AS 3700.

A3.3 Evaluation of slenderness ratio

The slenderness ratio of a member about a given principal axis shall be as follows:

For a vertical member that is laterally supported along one or both of its top and bottom ends:

$$S_r = \frac{a_v h}{t} \qquad \text{(Eq. A1.3)}$$

where

a_v = 0.75 for a member laterally supported and rotationally restrained at both top and bottom;

= 0.85 for a member laterally supported at both top and bottom and rotationally restrained at only one of these;

= 1.00 for a member laterally supported and rotationally free at both top and bottom;

= 2.00 for a member laterally supported and rotationally restrained at only its bottom.

A3.4 Maximum slenderness ratio for unreinforced earth walls

Maximum slenderness ratio for unreinforced earth walls S_r shall be as in accordance with Table A2.

Table A2 – Maximum slenderness ratio for unreinforced earth walls

Situation	Earthquake hazard factor (Z)	
	Z < 0.2	Z > 0.2
Unreinforced loadbearing wall	8	6
Unreinforced non-loadbearing wall	10	8

C Table A2
The values in Table A2 are recognised good practice based on data from overseas codes and experience in New Zealand.

A4 Design for horizontal bending from transient out-of-plane forces

A4.1 General

The design of an unreinforced earth wall, or portion thereof, to withstand horizontal bending from out-of-plane wind loads, earthquake loads, or similar forces of a short-term transient nature, shall comply with A4.2 or A4.3 provided that:

(a) For earth brick walls, the wall has all perpends completely filled; and

(b) For pressed-earth brick or adobe, the wall, or that part being designed for horizontal bending, has a minimum of four contiguous courses of earth bricks acting together in horizontal bending.

A4.2 Horizontal bending with tension stresses permitted

A wall complying with the requirements of A4.1 shall be proportioned so that the following relationship is satisfied under each combination of simultaneously acting design horizontal bending moment (M^*_{dh}):

$M^*_{dh} \leq M_{ch}$ ....(Eq. A1.4)

where

$M_{ch} = 0.40\ \phi\ f_{et}\ Z_u$ for earth brick walls ....(Eq. A1.5)

$M_{ch} = \phi\ f_{et}\ Z_u$ for rammed or poured earth walls ....(Eq. A1.6)

CA4.2
The factor of 0.40 allows for bricks laid in overlapping bond which, conservatively, have 40% of the wall height available to resist horizontal moments when the bending strength of the mortar is ignored.

A4.3 Out-of-plane strength for vertical bending

The lateral out-of-plane (face) load strength of unreinforced earth walls spanning vertically shall be calculated using the analysis methods of *Seismic assessment of existing buildings, section C8: Unreinforced masonry buildings*. (See 'Other publications' in the list of referenced documents at the front of this standard.)

A5 Shear

A5.1 Shear capacity

The design of an unreinforced earth wall subject to shear forces, with or without simultaneous compressive forces acting across the shear plane, shall be such that the following relationship is satisfied under each combination of simultaneously acting design shear force, V^*, and (minimum) compressive stress (f_d) acting at the cross section under consideration:

$V^* \leq \phi [f_{es} A_b + k_v f_d A_b]$ ....(Eq. A1.7)

or

$V^* \leq 5 \phi f_{es} A_b$ ....(Eq. A1.8)

whichever is less.

Limited ductility seismic design principles shall not be applied to unreinforced earth.

CA5.1
The factor of 5 term in Equation A1.8 places an upper limit on the influence of vertical load. Vertical reinforcement pretension may be taken into account in calculating f_d provided the pretension is maintained after shrinkage has taken place.

A5.2 Shear factor (k_v)

The value of k_v for use in A5.1 shall be:

(a) At membrane type damp-proof courses, flashings, and similar locations having low friction resistance:

k_v = zero ....(Eq. A1.9)

(b) At mortar bed-joints:

k_v = 0.30 ....(Eq. A1.10)

CA.5.2
Testing may be used to establish values for k_v that are different from those given by A5.2. Such testing is outside the scope of this standard. The value of k_v from Equation A1.9 necessitates reinforcement penetrating damp-proof membranes to ensure shear continuity.

A5.3 Development of longitudinal shear strength

Where it is necessary to transfer shear forces across wall intersections and vertical mortar joints in earth brick construction, the bonding or tying across the shear plane shall be an overlapping bond.

A5.4 Design of shear walls

A5.4.1

Shear walls shall be designed to comply with A2 to A4.3 and A5.1, and in accordance with the provisions of A5.4.2 and A5.4.3.

A5.4.2 Two or more shear walls acting together

Where lateral forces are resisted by two or more shear walls acting together, the load and force actions shall be distributed between the shear walls using structural analysis principles, taking into account the relative stiffnesses of the walls under these actions, and the effects of openings, if any, in the walls.

A5.4.3 Design for compression and in-plane lateral forces

The strength capacity of a shear wall under compression and flexure in the direction of the length of the wall shall be assessed on the basis of the properties of the whole monolithic cross section of the wall.

CA5.4.2

Where 'T' or 'L' sections are considered, there should be adequate shear connection strength between the elements and a conservative approach should be taken. Such considerations are outside the scope of this appendix.

NOTES

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