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DRAFT

New Zealand Standard

Committee:
P4298 Earth Building

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Standards New Zealand

PO Box 1473, Wellington 6140

Public comment information

Status

This document is a proposed New Zealand standard under the Standards and Accreditation Act 2015. Issued as a draft in this form, it provides the required statutory opportunity for consideration and comment by the bodies and persons having an interest in the standard.

How to comment

Closing date for comments **26 May 2024**.

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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DZ 4298

New Zealand Standard

Materials and construction for earth buildings

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Related documents

Reference is made in this standard to the following:

New Zealand standards

NZS 3101:2006	Concrete structures standard
NZS 3109:1997	Concrete construction
NZS 3124:1987	Specification for concrete construction for minor works
NZS 3603:1993	Timber structures standard
NZS 3604:2011	Timber-framed buildings
NZS 4210:2001	Masonry construction: Materials and workmanship
NZS 4251:- - - -	Solid plastering
Part 1:2007	Cement plasters for walls, ceilings and soffits
NZS 4297:2020	Engineering design of earth buildings
NZS 4299:2020	Earth buildings not requiring specific engineering design
NZS 4402:- - - -	Methods of testing soils for civil engineering purposes – Soil compaction tests – Determination of the dry density/water content relationship
Test 4.1.1:1986	New Zealand standard compaction test
NZS 7601:1978	Specification for polyethylene pipe (Type 3) for cold water services

Joint Australian/New Zealand standards

AS/NZS 1170:- - - -	Structural design actions
Part 0:2002	General principles
AS/NZS 1547:2012	On-site domestic wastewater management
AS/NZS 2053:- - - -	Conduits and fittings for electrical installations –
Part 1:2001	General requirements (Reconfirmed 2016)
AS/NZS 4671:2019	Steel reinforcing materials

Australian standard

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; Clauses C1 to C6 Protection from fire; Clause E1 Surface water; Clause E2 External moisture; Clause E3 Internal moisture; and Clause H1 Energy efficiency, Ministry of Business, Innovation and Employment, 2019.

CSIRO Australia Publication Bulletin 5 Earth Wall-Construction Fourth Edition by G F Middleton, revised by L M Schneider in 1987

Guelberth, C R, and Chiras, D. *The Natural Plaster Book*. USA: New Society Publishers, 2003.

Middleton, G F, revised by Schneider, L. CSIRO Australia Publication Bulletin 5 Earth Wall-Construction. Fourth Edition, 1987.

Moisture Properties of Plaster and Stucco for Strawbale Buildings https://tallerconco.org/wp-content/uploads/2017/05/Straube_Moisture_Tests.pdf.

Ofverbeck, P. 'Ofverbeck Power Method: Small Sample Control and Structural Safety', Rep.TVBK-3009, Division of Structural Engineering, Lund Institute of Technology, Lund, Sweden. As reported by Hunt, R D, and Bryant A H 'Statistical Implications of Methods of Finding Characteristic Strengths', *Journal of Structural Engineering*, Vol.122 No.2, Feb. 1996, pp. 202–209.

USA Uniform Building Code 1982 (International Conference of Building Officials, Whittier, California)

Weismann, A, and Bryce K. *Using Natural Finishes: Lime and Clay Based Plasters, Renders and Paints – a Step-by-Step Guide*. UK: Green Books, 2008.

New Zealand legislation

Building Act 2004

New Zealand Building Code

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.co.nz.

Review of standards

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

Foreword

The first edition of this suite of three standards, NZS 4297, NZS 4298, and NZS 4299, published in 1998 and updated in 2020, has been a core resource for building consent authorities determining compliance with the New Zealand Building Code (NZBC) and has 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 decarbonising of the built environment is under scrutiny. Earthen materials are minimally processed, have low toxicity, and are available locally. These standards will encourage and enable the uptake of local earthen 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 Fire safety, 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, that provide improved thermal and seismic performance, are included in the revised standards, along with the more traditional, dense earthen materials. Acceptable Solution E2/AS2 third edition amendments 4 and 5 to the 1998 standards are now incorporated into these standards.

NZS 4297:2020 *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 unreinforced and 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 that need to be considered apart from other forms of masonry.

NZS 4299 (as described below) 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 4298:2020 *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 earthen 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 4299:2020 *Earth buildings not requiring specific engineering design* 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 weather tightness are covered by a methodology that relates required durability test results to wind driven rain exposure of any particular building site.

The revised edition of NZS 4299 includes new 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 is 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 to achieve durable, weathertight, and successful buildings. This will encourage the uptake of local earthen 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 chair of the 1998 committee), their nominating organisations, of Standards New Zealand, and of 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 his 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 limited scope revision has 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.

Outcome statement

NZS 4298 sets minimum standards for earthen materials. When applied by architects, designers, builders, engineers, and apprentices, NZS 4298 provides these users with a cost-effective means of compliance, and practical guidance on earthen materials, their testing, and how to use them, when constructing earth buildings.

It is intended that NZS 4298 will be considered for referencing in Acceptable Solutions and Verification Methods which 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 4298 needs to be read and applied alongside NZS 4297 and 4299, standards that provide design details and other criteria for building successful earth buildings.

1 GENERAL

1.1 Scope and objective

1.1.1 *Scope*

This standard sets out requirements for the materials and construction requirements for the use of unfired earth in the form of adobe, pressed earth brick, rammed earth, cob, poured earth, and in-situ adobe including both low-density earth and heavy earth. It also includes a section on surface coatings. This standard applies to buildings that are designed in accordance with NZS 4297 and NZS 4299.

C1.1.1

This standard is intended to be referenced by the New Zealand Ministry of Business, Innovation and Employment as means of compliance with the New Zealand Building Code (NZBC). NZS 4297 is intended to be referenced as a verification method and NZS 4299 is intended to be referenced as an acceptable solution, as were the 1998 editions of these standards. NZS 4297 and NZS 4299 both depend on this standard, NZS 4298, for the materials and construction of earth buildings.

1.1.2 *Objective*

The objective of this standard is to provide a means of compliance with the materials and construction requirements of structures designed in accordance with either or both NZS 4297 and NZS 4299.

1.1.3 *Standard grade and special grade earth*

Two grades of earth wall construction are provided for in this standard: standard grade and special grade.

Standard grade provides minimum properties for material for:

(a) The construction of single-storey earth buildings in accordance with NZS 4299 and that are subject to the limitations imposed by clause 1.2 of NZS 4299; and
(b) Use in buildings that are subject to specific engineering design (SED) using the design strengths defined in clause 2.4.2.3 of NZS 4297.

Standard grade earth wall construction provides minimum properties for earth wall construction for use in buildings that are constructed in accordance with NZS 4297 or NZS 4299. Such buildings will satisfy the requirements of the clauses of the NZBC as set out in NZS 4297 or NZS 4299.

Special grade earth wall construction is material that meets minimum properties that are defined in the design and is applicable to buildings subject to SED as set out in NZS 4297.

Special grade earth wall construction shall meet or exceed all requirements for standard grade earth wall construction. Buildings incorporating special grade earth wall construction will satisfy the requirements of the clauses of the NZBC as set out in NZS 4297.

1.1.4 *Earth wall density*

Two densities of earth wall, low-density and heavy-weight, are provided for adobe and cob. Low-density and heavy-weight materials within the same wall panel are outside the scope of this standard. Buildings are able to have different densities within the same building subject to SED.

Dense earth-cement mixtures that contain more than 15% by volume of cement are outside the scope of this standard.

Low-density earth-cement mixtures that contain more than 15% weight of cement are outside the scope of this standard.

1.1.5 *Earth mortar exclusions*

Cement or lime stabilised earth mortars are outside the scope of this standard.

C1.1.5

The performance of cement/lime stabilised earth mortars under seismic loads has been observed to be unreliable so the use of such mortars is subject to specific design, including bond wrench test results. See Appendix N. The use of such mortars with pressed earth bricks is not recommended. See 5.5.1. The use of stabilisers in earth-based mortars is outside the scope of this standard.

1.2 Interpretation

1.2.1 *Shall and should*

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

1.2.2 *Commentary clauses*

Clauses prefixed by 'C' and printed in italic type are comments, explanations, summaries of technical background, recommended practice or suggest 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 the mandatory requirements of compliance within this standard. The standard can be complied with if the comment is ignored.

C1.2.2

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 experience and as a means of meeting the challenge of writing this as a performance-based suite of earth building standards. Accordingly, the unusual format of having commentary clauses that have no corresponding mandatory clause has been adopted.

1.2.3 *Reference documents*

The full titles of reference documents cited in this standard are given in the list of related documents immediately preceding the foreword.

1.2.4 *Nominal dimensions*

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

1.2.5 *Normative appendices*

The term 'normative' has been used in this standard to define the application of the appendix to which it applies. A 'normative' appendix is an integral part of a standard and contains requirements.

1.3 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

Aggregate — Collective name for inert materials, for example, sand and gravel, which when mixed with clay and possibly additional binding agents or fibres is used to produce earth-based building materials. Silt may be present as an inert filler in earth building material

Batch — A finite quantity of material, bricks, or other items, sampled or produced at any one particular time

Bond, overlapping — The technique of bond where 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

Brick — A discrete unit of earth masonry

Building consent authority — A building consent authority as defined in the Building Act and includes a territorial authority or private body acting within the scope of their approval

Cell — A hole through or along an earth brick unit in the plane of a wall

Characteristic strength	An estimate of the lower 5% value determined with 75% confidence from tests on a representative sample of full-size specimens
Chase	A groove cut into a constructed wall to accommodate services
Clay	A fine-grained, natural, inorganic soil composed primarily of hydrous aluminium silicates with grain diameters less than 0.002 mm
Cob	A method of earth construction that involves placing a stiff mix of moist, unstabilised clay, silt, and sand directly into place in walls without the use of formwork or mortar. The mix can also contain gravel, straw, other fibres, pumice, or perlite
Cold joint	In rammed-earth, cob, 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
Construction joint (in earth walls)	Joint made within a rammed-earth wall panel during the production of the wall as a result of the stepwise building procedure
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 layer of durable water-vapour barrier material placed between building elements to prevent the passage of moisture from one element to another.
Diaphragm	A building element such as a floor or ceiling capable of transferring loads in its own plane to boundary members
Durable	Resistant to wear and decay. Durability has a corresponding meaning
Earth (for earth building)	Natural subsoil comprised 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 of from 800 to 2200 kg/m^3 inclusive
Erosion	The physical and chemical processes by which earth building material is worn away. It includes the processes of weathering and mechanical wear
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

Gable	Outside wall between the planes of the roof and the line of the eaves
Gravel	Soil with particle sizes larger than 2.0 mm
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
Heavy earth or Heavy-weight earth	Adobe, cob, pressed earth bricks or rammed earth with a dry density greater than 1400 kg/m^3
Hydrated lime	Quicklime that has reacted with water ($Ca(OH)_2$). Also called slaked lime. See Lime
In-situ adobe	A method of earth construction where a stabilised adobe-like brick is cast directly into place on a wall
Light earth method (LEM)	A mixture of light earth tamped into formwork to form an insulated wall between or around structural members and around wall openings. See NZS 4299 Appendix D
Light earth	A mixture of straw or other natural fibres and clay slip tamped to form an insulated wall between or around structural members and around wall openings. Also known as 'straw-clay', 'clay straw', 'light LEM', 'clay-fibre', 'straw light clay (SLC)', 'light straw clay', or 'chip and slip'. Other natural fibres, such as wood shavings, hemp shivs or reeds, may be incorporated or substituted. Low-density minerals aggregates, such as pumice, scoria or vermiculite, may also be included.
Lime	Quicklime or burnt lime (CaO) or hydrated (slaked) lime ($Ca(OH)_2$) but not agricultural lime ($CaCO_3$). Agricultural or gardening lime is crushed limestone or other calcium carbonate natural material and is not relevant to earth building apart from occasional use as a sand or gravel aggregate
Lime putty	Hydrated (slaked) lime ($Ca(OH)_2$) that has been stored under water
Low-density earth (also known as low density earth) includes structural light adobe (SLA) or structural light cob (SLC)	Adobe or cob used structurally with a dry density of from 800 to 1400 kg/m^3
Modulus of rupture	See Flexural tensile strength
Moisture content	The amount of water contained in soil or earth material expressed as the weight of the water divided by the weight of the dry soil or earth material in percentage terms
Mortar	The bedding material in which earth brick units are bedded
Mortared couplet	Stack bonded piers two bricks high
Mud brick	See Adobe

Perm	A unit of measurement of permeance for which there are several forms, for example, US perm and metric perm. This standard uses the 'SI unit' ng/Pa.s.m^2. This is 10^{-9} smaller than the SI unit to provide a unit useful in practice. Conversion factors are given in commentary clause, C8.5.4
Permeability (water vapour permeability)	A material property, independent of thickness, that measures its ability to allow the transmission of water vapour. The units are ng/Pa.s.m. See also Permeance
Permeance (water vapour permeance)	A measure of the ease of water vapour flow through an area of either a particular thickness of a material (such as a coating) or of a complete, multilayer building element. Units, referred to here as SI units, are ng/Pa.s.m^2. For a homogeneous material, permeability divided by its thickness gives the permeance
Perpend	The vertical joint between two bricks
Plaster base coat	A layer of plaster applied before the finish coat, usually straight to the textured substrate
Plaster finish coat	The final coat of plaster applied over the previous coat(s) and finished within the specified surface tolerances.
Plasticity	The ability of a moist soil to be deformed and hold its shape
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
Quicklime	Calcium oxide (CaO) made by the thermal decomposition of limestone or other materials containing calcium carbonate in a lime kiln. See Hydrated lime
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
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
Sand	Individual rock or mineral fragments that range in size from the upper limit of silt (0.06 mm) to the lower limit of gravel (2.0 mm)
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)
Skin	A continuous vertical tier of bricks one unit in thickness
Slaked lime	See Hydrated lime
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
Specific engineering design (SED)	Specific engineering design (SED) requires calculation and design beyond the scope of this standard The design required is not necessarily design by engineers but may include architects and licensed building practitioners in an appropriate area of practice
Stabilised adobe	Adobe bricks that have a stabiliser added, typically lime, cement, or asphalt emulsion
Stabilised pressed brick	Pressed brick that has had a stabiliser added, usually cement
Stabilised rammed earth	Rammed earth that has had a stabiliser added, usually cement
Stabiliser	A material that is used for stabilisation
Structural light adobe (SLA)	See Low-density earth also known as structural light adobe (SLA) or structural light cob (SLC)
Structural light cob (SLC)	See Low density earth also known as structural light adobe (SLA) or structural light cob (SLC)
Wall thickness	Minimum thickness of wall remaining after any chasing, raking or tooling of mortar joints but excluding the surface coating, if any

1.4 Abbreviations

The following abbreviations are used in this standard.

HDPE	High-density polyethylene
LEM	Light earth method
NZBC	New Zealand Building Code
SED	Specific engineering design
SLA	Structural light adobe
SLC	Structural light cob

1.5 Construction monitoring

1.5.1 *Adequate monitoring*

All stages of construction of a structure or part of a structure to which this standard applies shall be adequately monitored by a person who, on the basis of experience or qualifications, is competent to undertake the monitoring to ensure compliance with this standard.

1.5.2 *Extent of monitoring*

The extent of monitoring to be undertaken shall be nominated in plans or specifications, taking into account those materials and work quality factors that are likely to influence the ability of the finished construction to perform in the predicted manner.

1.6 Construction

1.6.1 *Components*

All construction shall be such that each component of an earth element complies with this standard and furthermore that the finished earth element also complies with this standard.

1.6.2 *Inspection*

Where brick or block or discrete earth elements, such as bricks or blocks, are produced they shall be inspected as required by 1.4 for acceptable properties and then if approved, laid into a wall.

> ***C1.6.2***
>
> *The procedure of 1.5.2 is not possible with the rammed-earth building technique as large panels may be constructed at one operation and often no part of the rammed-earth wall is visible until the formwork is removed.*

1.7 Application

1.7.1 *Rammed earth*

Rammed earth shall comply with sections 2 and 3 of this standard.

1.7.2 *Adobe*

Adobe shall comply with sections 2 and 4 of this standard.

1.7.3 *Pressed earth brick*

Pressed earth brick shall comply with sections 2 and 5 of this standard.

1.7.4 *Cob*

Cob shall comply with sections 2 and 6 of this standard.

1.7.5 *Poured earth and in-situ adobe*

Poured earth and in-situ adobe shall comply with sections 2 and 7 of this standard.

1.7.6 *Grouting cavities*

Where grout or mortar filling of cavities for reinforcing bars is required, bricks shall be of such type and arrangement that will be conducive to the complete filling of all the grouted cavities.

1.7.7 *Surface coatings*

Surface coatings shall comply with section 8 of this standard.

1.7.8 *Earth floors*

Earth floors shall comply with section 13 of NZS 4299.

2 MATERIALS AND CONSTRUCTION

2.1 General

> ***C2.1.1 General***
>
> *This section acknowledges that the quality of materials and construction employed in the production of unfired earth walls has a direct bearing on whether those walls meet the structural and durability requirements of the New Zealand earth building standards. The intent of this section is to define the materials and practices to produce walls that, when designed in accordance with either or both NZS 4297 and NZS 4299, comply with the performance requirements of the NZBC as appropriate. Earth buildings can fully comply with this standard yet exhibit a wide range of surface texture and colour.*

The skilled nature of some of the construction requirements in some forms of earth building and in many aspects of general earth building should not be underestimated.

It is not the intention of this standard to produce buildings of uniformity or sameness of appearance. An extremely wide range of colours, textures and appearance is an integral part of earth buildings.

While no two earth buildings may be identical, it is the intention of this standard to achieve a reasonable homogeneity and evenness within an individual building.

C2.1.2 Criteria not exhaustive

The provisions of this section do not constitute a full specification for contractual purposes. Requirements beyond the performance criteria of this standard (such as surface texture and colour variations) should form part of a specification. The general nature of many provisions of this standard is due to factors that include:

(a) The wide range of soil types with or without admixtures that can be successfully used given appropriate design and consideration of rainfall;

(b) It is possible to test samples of soil and walling units in a laboratory, but it cannot always be assumed that the results are necessarily indicative of long-term performance of an earth building;

(c) At the time of writing this standard, there are no nationally accredited building trade training modules in existence in New Zealand that relate specifically to earth building, nor are there industry agreed standard project specifications. There are, on the other hand, widely differing perceptions within the community of what constitutes acceptable or desirable practice.

2.2 Soil

2.2.1 *Scope*

Soils that are able to be used to manufacture earth building materials that satisfy the testing requirements of 2.5 and which satisfy the requirements of 2.2.2 are within the scope of this standard.

C2.2.1

Soil falling within the scope of this standard contains clay and silt together with aggregate that is of a wide range of particle sizes. The proportions of clay, silt, and aggregate will vary depending on the nature of minerals involved and the earth building medium being used.

Tests in Appendix A and Appendix B are useful as a preliminary assessment of the suitability of a prospective soil source for earth building by giving an approximate proportion of clay present.

2.2.2 *Outside of scope*

Soils that shall not be used include the following:

(a) Those containing organic matter of a type prone to rot or breakdown within the wall;

(b) Those containing water-soluble salts to an extent that will impair the strength or durability of a wall;

(c) The sand shall not contain salt and so must be washed if sourced from a marine environment;

(d) Those containing aggregate large enough to impair the strength or homogeneous structural performance of the wall. Such soils can be suitable if screened;

(e) Soils that dry to form an earth building material with a surface containing fine cracks. The cracks are generally short with a random orientation. The surface layer will continue to flake off, particularly if there are changes in moisture content; and

(f) Soils that fail the wet/dry appraisal test given in Appendix J.

C2.2.2

Most aggregates should generally not be larger than 20 mm but may occasionally be 50 mm. Depending on the type of construction, larger aggregate can affect appearance, cause cracking, make surface finishing difficult, or make mixing difficult. A broad range of particle sizes is needed rather than a single size sand or aggregate to ensure that the mix will bind. Bricks with large aggregate can be brittle.

The addition of aggregates has been found to increase durability of many mixes, and also helps limit shrinkage.

2.2.3 *Other materials and proprietary products*

Other materials and proprietary products that totally replace the binding properties of clay and silt or the strength or filler properties of aggregate with other substances are outside the scope of this standard.

2.3 Materials other than soil

2.3.1 *Reinforcement*

Steel bar, wire, and mesh reinforcement shall be in accordance with 2.8.

Steel reinforcement is to be protected in accordance with 2.8.7 from corrosion or from other deterioration. Reinforcement shall be positioned in accordance with the design document prepared in accordance with NZS 4297 or NZS 4299.

C2.3.1

The role of reinforcement is to provide tensile strength to a material with otherwise low tensile strength but with significant compressive strength.

2.3.2 *Aggregate*

Aggregate or filler is composed of small gravel, coarse and fine sand, and larger silt particles. These are the 'stable' component of the earth wall and normally contribute the bulk of the mass. They are characterised by insufficient cohesion to produce minimum bonding strength for a wall.

Aggregate is not to contain salt and shall be washed if sourced from a marine environment.

C2.3.2

The addition of aggregates has been found to increase durability of many mixes, and also help limit shrinkage.

2.3.3 *Water*

Water for use in earth building materials shall be of potable quality.

2.3.4 *Admixtures and stabilisers*

Permitted additives to naturally occurring soils to formulate earth building materials are straw or other natural fibres, such as cellulose or wood shavings, sand, gravel, and Portland cement.

C2.3.4

The two main purposes of these additions are to control the instability of the clay particles and to improve the water resistance of the finished wall. Other characteristics such as hardness and compressive strength are also affected. Curing times and conditions also vary according to the additive used.

One role of the clays in soil is to bind the aggregate together. The strength of this bonding will vary with changes of moisture content and the expansiveness of the clay itself. In some applications, the natural strength or durability characteristics of earth walling may be enhanced by the use of admixtures such as gravel, lime, sand, clay, cement, straw, or other fibres or by the blending of various soil types.

Polypropylene fibres may also be added to some mixes. Fibres also help control cracking as materials dry and can also act in a similar way to aggregates by helping to increase durability and/or limit shrinkage.

2.3.5 *Moisture content*

During the construction of an earth wall or the making of bricks, there shall be sufficient water present to enable the fines to bind the aggregate together and to hydrate any cement used. A moisture content test for rammed earth mixture is provided in Appendix I. Other materials will not form earth wall material that complies with the testing requirements of 2.5 if moisture content is not within an appropriate range.

2.3.6 *Storage and handling of materials*

All materials including admixtures shall be stored in such a way as to avoid contamination, premature degradation, or chemical reactions. Steel reinforcement shall be protected from deterioration due to corrosion.

C2.3.6

Soils to be screened or blended are best stored in their dry state.

2.3.7 *Joints*

Joints shall conform to 2.14.

2.3.8 *Curing and drying*

2.3.8.1

Adobe and pressed earth bricks shall be cured and/or dried before laying. Minor surface wetting after curing and drying need not delay laying and it is noted that this is required by 4.9.1 and 5.5.2. Except as required by 2.3.8.2 and 2.3.8.3, curing shall be carried out by air drying for a minimum of 28 days in an exterior environment that is protected from strong winds and rain. They shall be protected from strong wind and direct sunlight for the first 4 days of curing. Time during which the temperature is below 5°C shall not be included in the 28 days.

C2.3.8.1

Full drying will be accompanied by full shrinkage of the earth material. It should be noted that neither full drying nor full shrinkage will necessarily have taken place in earth walls prior to completing adjoining construction. Continued shrinkage can take place for an extended period of up to six months.

Bricks should be laid when dry.

The curing of the wall, or the bricks, is best done slowly, thereby avoiding the formation of large cracks. Adobe, cob, and poured earth are particularly susceptible to this, as larger quantities of water are used than in either pressed bricks or rammed earth.

2.3.8.2

Materials incorporating Portland cement shall have a minimum of one week of damp curing before air drying is commenced in an exterior environment that is protected from direct sunlight, strong winds, and rain.

2.3.8.3

Materials incorporating hydrated lime shall be damp cured for a minimum of three weeks before air drying is commenced in an exterior environment that is protected from direct sunlight, strong winds, and rain.

2.3.8.4

Shrinkage due to curing shall be allowed for in construction details and programme.

C2.3.8.4

Curing is the process of chemical changes involving water together with cement, hydrated lime, and clay followed by the evaporation of water from the brick or completed wall. Curing is normally accompanied by shrinkage and a consequent increase in dry density and an increase in the bonding strength between particles. Earth walls cure over extended periods of time. On those surfaces subject to repeated cycles of sun and rain, a hardened, more water resistant surface 'skin' or 'rind' of exposed larger particles can be observed to develop on some earth materials.

2.3.9 *Services, fittings, chases, sleeves, conduits, pipes*

2.3.9.1

Water pipes may not be embedded within earth wall but may be within a conduit through the wall.

C2.3.9.1

As a general rule, it is better to build all wires, pipes, ducts, and rods into the wall during construction. But as this is often not possible, chasing to let in pipes and wiring is common. Embedment of water pipes within an earth wall is not recommended because of the potential for leaks and the difficulty of maintenance. A 30 mm deep chase to accommodate these is necessary. Some service connections, such as the spool of wires into a meter box and lagged hot water pipes, are too large to be chased in. Chasing down a wall also leaves a scar that may be difficult to eradicate in the finished wall, unless it is being plastered.

2.3.9.2

Detailing shall take account of shrinkage strains and the effect of embedded inclusions such as conduits, sleeves, chases, pipes, and fittings. Thermal expansion and contraction of service pipes shall be accommodated. All embedded pipes shall be fully lagged. At changes in direction of embedded pipes, compressible material shall be placed in line with each straight section of pipe sufficient to accommodate any thermal expansion and contraction.

2.3.9.3 Services locations

Holes horizontally through walls made for service inserts for drainage, water, electricity, or other services shall not be wider nor higher than either 200 mm or more the 10% of the wall panel length. There shall be not more than one such hole larger than 100 mm per panel.

Service cables that can impose loads on walls shall be adequately anchored.

Except where chasing complying with 2.3.9.4 is used, vertical or horizontal service ducts (conduits) except for vertical electrical conduits as provided for below, may only be inserted in the central third of the wall thickness and shall not exceed 10% of the wall thickness for rammed earth or 20% for adobe or cob.

Vertical electrical conduit may be placed in the same hole as vertical reinforcing.

Penetrations entering the building below a damp-proof course shall be sealed so as to prevent the entry of moisture, vermin, and insects.

2.3.9.4 Chasing

Chasing shall have a maximum width and depth of 30 mm and shall be located more than 300 mm from the ends of walls. Such cases must not be on both sides of the wall at the same location. Where this is required, such chases must be separated horizontally by at least 300 mm.

2.3.10 *Cement grout*

Cement grout shall be in accordance with NZS 4210.

2.3.11 *Mixing of earth*

2.3.11.1

All parts of the earth mix including any admixtures shall be thoroughly broken down to a homogeneous mass of consistent composition, texture, and moisture content prior to use.

2.3.11.2

Earth containing Portland cement as a setting admixture shall be used within 45 minutes after contact between the cement and either water or moist earth.

C2.3.11.2

Consistency of mix is vital for all successful earth building. Otherwise, potentially good earths can produce poor walls for want of thorough soaking and mixing.

2.4 Mortar

C2.4

Mortar is of major importance in the overall performance of earth walls where it is used.

2.4.1 *Measurement of materials*

2.4.1.1

Measurement of components shall be carried out with an accuracy appropriate to achieving consistent mortar properties.

2.4.1.2

All measurements shall be carried out by volume. All mix proportion measurements in this standard are specified by volume.

C2.4.1.2

Measurements by volume should be in buckets or boxes of known volume with the surface struck off level.

2.4.2 *Composition and mixing*

2.4.2.1

Mortar shall be either:

(a) Earth-based mortars; or
(b) Sand/lime/cement mortars.

The use of stabilisers in earth-based mortars is outside the scope of this standard (see 1.1.5) therefore cement or hydrated-lime stabilised earth mortars shall not be used.

C2.4.2.1

If the composition of the mortar is similar to that of the brick, the mortar bond can be improved, and differential weathering is avoided.

If rubdown of the wall is desired, it is easier if the mortar joints are still soft.

Cement-stabilised or lime-stabilised earth mortars have been found not to perform adequately in service.

2.4.2.2

Mortar shall contain no particles larger than half the minimum joint thickness.

2.4.2.3

Mortar containing cement or lime shall not be reconstituted once it has taken its initial set.

2.4.2.4 Sand/lime putty/cement mortars

The sand/lime putty/Portland cement ratio shall be within the range 9:2:1 to 9:3:0 (sand/lime putty/Portland cement) by volume. Hydrated lime shall be pre-soaked for 24 hours minimum to form the lime putty. The mortar shall be mixed to obtain a homogeneous, lump-free mixture.

The use of cement or hydrated lime stabilisers in mortars containing earth is outside the scope of this standard (see 1.1.5)

C2.4.2.4

Commercially available bricklaying sand is generally adequate. Lean sands are acceptable – they are harder to work with and can require the addition of a small amount of plasticiser.

The sand is not to contain salt to comply with 2.2.2(c) and so may need washing. Any sand from a coastal or marine environment needs to have been washed.

Mechanical mixing of mortar ingredients is the preferred method.

If mortar is mixed by hand, then mixing should be thorough and complete. In most cases a mechanical mixer is required to distribute the stabiliser evenly throughout the mix.

Accurate measurement of materials is needed to obtain consistent mixes where cement or hydrated lime is used.

2.4.2.5 Earth-based mortars

Mortar mixed from the same earth mix as the bricks need not be tested except for the shrinkage test as required by 2.5.

Mortar made from a different earth mix to that from which the bricks are made shall be tested as required for the bricks under 2.5.

For the purposes of this clause, the sieving out of particles larger than 8 mm shall not be considered as changing the composition of the earth so does not require additional testing.

C2.4.2.5

Mortars high in clay may need tempering with sand and/or straw if there is excessive cracking of the mortar when dry. Straw is only used in mortar if there is straw in the bricks being laid.

Mortars high in sand will need the addition of suitable clay if the mortar exhibits a 'crumbly' character when dry.

The ratios of sand to clay that give a workable mixture and meet the required test results should be worked out by trial.

If earth mortar is mixed by hand, then it is recommended that the mortar be mixed to the required consistency at least 24 hours before being used to ensure adequate and complete soaking of the earth. A further light mixing might be necessary immediately before use. More water might have to be added if drying out has occurred. Mechanical mixing of mortar materials is the preferred method.

2.4.3 *Properties*

2.4.3.1

This clause applies to both earth-based mortars and lime-cement-based mortars.

2.4.3.2

Mortars shall comply with the appropriate testing requirements of 2.5.

2.4.3.3

Mortars shall have the minimum moisture content required for workability.

2.4.3.4

The mortar shall be mixed to a consistency that is pliable enough to facilitate complete bedding of the earth bricks. The mortar plasticity shall be stiff enough to support the earth brick when laid without slump occurring under the weight of the brick alone but pliable enough to allow for the earth bricks to be pressed into their final position.

C2.4.3.4

Mortars should not be excessively wet. They should be wet enough to facilitate installation of the earth bricks and provide complete bedding without exhibiting excessive slumping.

2.4.3.5

In external applications where no render or other protective surface is to be applied and the wall is subject to wind-driven rain then any cracking of the mortar at the brick-mortar interface, or holes in the mortar surface, shall be repaired using the same mortar materials.

C2.4.3.5

The mortar should form an adequate bond with the earth bricks when completely dry.

Minor crazing of the finished mortar surface when completely dry is generally of no concern. Minor crazing acts as a key for any render coating applied.

Elimination of cracks ensures there is no concentration of water within the wall extremities.

2.4.3.6

The general requirements of mortars are:

(a) They are of sufficient strength to support the wall;
(b) They do not exhibit permeability to a degree that will allow the ingress of water;
(c) The bed thickness is not less than 10 mm for lime-cement mortars or 15 mm for earth-based mortars; and
(d) The bed thickness is not greater than 20 mm for lime-cement mortars or 35 mm for earth-based mortars.

C2.4.3.6

Further desirable properties of mortar are as follows:

(a) It does not exhibit excessive cracking;
(b) It bonds adequately with the earth bricks; and
(c) It needs to contain sufficient fines for good bonding, but also enough sand to facilitate spreading.

2.4.4 *Construction*

2.4.4.1

The subclauses of 2.4.4 apply to all mortars.

2.4.4.2

Mortar beds shall be full width and flush except as provided by 2.4.4.3. Ledges shall not be left on horizontal mortar joints.

In all cases the surface finish of the mortar joints shall be smooth, and all holes filled, unless the wall is to be plastered after the bricklaying is complete, when the finish on the wall shall be such that there is sufficient keying for the bonding of the plaster.

C2.4.4.2

Where the bricks are exposed, it is good practice if the walls are finished flush or 'bagged off'.

This is best achieved by either tooling the joints smooth, or if bagging, by a rub down of the wall at the end of the day's laying, while the mortar is still soft and easily moulded.

In general, the same good quality construction that applies to other bricklaying insofar as the mixing, installation, and final finishing of mortars should also apply to mortars used for adobe and pressed brick laying.

Mortar beds should be full to ensure adequate support of the earth bricks and to achieve maximum possible bonding.

The finish of the mortar should be smooth and completely bonded to the earth brick surface. There should be no holes or cracks in unprotected external surfaces. Ledges are not to be left on horizontal mortar joints in such a way as to catch and hold water running down the face and then soaking into the wall.

If plaster is to be applied to the earth brick and mortar surface, then it is recommended that the wall surface be trimmed flush and not washed down to assist with the provision of keying for the plaster.

2.4.4.3

Where mortar joints in walls are to be raked, the structural effects of the raking shall be taken into account by SED in accordance with NZS 4297 and relevant details shall be included in the plans and specifications.

C2.4.4.3

Where earth bricks are used in a loadbearing capacity, any raking of the mortar joints should only be light so as to ensure that the structural integrity of the wall is not affected.

Where earth bricks are used in non-loadbearing applications, the depth of raking of wall surfaces is not as critical as in loadbearing applications but should not be so excessive as to reduce the structural integrity of the wall below the required minimum for the particular application.

In both loadbearing and non-loadbearing applications raking of mortar joints in external wall surfaces subject to wind-driven rain is acceptable provided that all surfaces of the finished wall do not concentrate and hold moisture.

2.4.4.4

Bricks shall be moistened before laying as required by 4.9.1 and 5.5.3.

C2.4.4.4

Moistening the bricks reduces the rate of drying of the mortar. Excessive moisture will reduce bond and increase shrinkage.

2.5 Materials testing for standard grade earth construction

Test procedures and the results required by this standard are detailed in Table 2.1. The minimum extent of testing required is given in 2.5.1 and 2.5.2.

C2.5

Both special grade and standard grade earth construction are expected to be widely used.

Standard grade earth construction is to be used for buildings constructed in accordance with NZS 4299. Standard grade earth construction may alternatively be the subject of SED in accordance with the design strengths given by Table 2.1 of NZS 4297.

It is necessary to demonstrate that earthen materials used (with or without admixtures) produce results meeting at least the minimum criteria of strength and durability set out in this standard. It is desirable that testing, wherever possible, takes place on the building site and is performed under the direction of the person responsible for the construction of the walling.

See C2.2.1 for reference to Appendix A for testing for guidance on clay content.

2.5.1 *Tests before commencing construction*

2.5.1.1

The tests indicated in Table 2.1 shall be carried out prior to work commencing on a building. Test results that meet or exceed the requirements of the relevant test shall be obtained. Records shall be kept that permit the identification of the earth building materials used and their proportions in each test specimen. The materials tested shall be representative of materials that are to be incorporated in the building. Earth building materials to be incorporated in a building shall comply with the testing requirements of this clause.

C2.5.1.1

Investigations of the building materials should be sufficiently detailed to match any earth building material likely to be used on a project. Materials with significant variations in properties can significantly affect test results.

Flexural tensile strength (modulus of rupture) is very variable with most results lying between 10% and 50% of compressive strength. The ratio depends on the type of brick and whether they are stabilised or not. The majority of results lie below 30% so a compressive strength multiplier of 3.5 times flexural tensile strength, based on unstabilised adobe, has been adopted as the benchmark.

Laboratory compression tests will give more consistent results.

2.5.1.2

Prior to being tested, samples shall be air dried for 28 days in an exterior environment that is protected from strong winds, rain, and, for the first 4 days, direct sunlight. Samples shall not be oven dried. These requirements for test samples are in addition to those of 2.3.8.

2.5.1.3

Where earth materials or components are produced at a fixed location remote from the building site, which is able to supply materials or components for more than one building, then the frequency of tests required by Table 2.1 shall be at the shortest interval between occurrences of any of the following:

(a) When the properties of the soil change;
(b) When the source of the earth changes;
(c) For adobe, every 5000 units;
(d) For pressed earth bricks, every 2500 units;
(e) For rammed earth, cob, poured earth, or in-situ adobe, every 50 m^3; or
(f) Annually.

> ***C2.5.1.3***
>
> *This provision is intended to apply to specialist manufacturers of earth wall materials.*
>
> *In commercial construction, tests are likely to be requested more often than the frequencies in Table 2.1.*

2.5.2 *Quality control tests during construction*

2.5.2.1

The tests indicated in Table 2.1 shall be carried out at the frequencies indicated in the table during earth building construction.

2.5.2.2

Where the results of a test fail to meet the requirements of the test then the material represented by the sample that failed shall be removed from the building unless further tests are conducted in accordance with the provisions of 2.5.2.3.

2.5.2.3

Further tests may be conducted on five random samples to be taken from the structure and that are representative of the material that previously failed the test. Results of the five tests shall be assessed in accordance with Appendix D and if the resultant value fails to meet the minimum requirements of the test, then the material represented by the samples that failed shall be removed from the building.

2.5.2.4

The results from all the relevant project-specific tests stated in Table 2.1 are to be recorded in a suitable report, as detailed in 2.5.2.5, which will be required to be provided to the appropriate building consent authority on request. A copy of all test results is to be kept on the construction site.

2.5.2.5

The record of project-specific tests is to include, where relevant, the job identifier, address, sample location, sample number, date mixed, mixed by whom, date sampled, sampled by whom, date tested, tested by whom, test used, test measurements, test result interpretation, and the name and signature of the competent and experienced person making the interpretation.

Table 2.1 Tests for standard grade earth construction

Property	Appendix clause	Pressed bricks	Adobe	Cob (Note 10)	Rammed earth	Poured earth and in-situ	Earth mortar (Note 8)	Frequency		Required result (Note 5)
								Prior to work start (Note 6)	During construction	
Compression or flexural tensile strength	E, G, O (Note 1)		✓	✓	✓	✓	✓	1 sample of 5 or more individuals	1 sample of 5 individuals for every 5000 bricks or part thereof (Notes 2, 3, and 7)	f_e > 1.4 MPa Heavy earth (Note 4) f_e > 0.9 MPa Low-density earth (Note 4) f_{et} > 0.40 MPa (lowest of 5 results) (tests G1, G2)
		✓						1 sample of 5 or more individuals	1 sample of 5 or more individuals for every 2500 bricks or part thereof (Notes 2 and 3)	f_e > 1.4 MPa (compression) (Note 4) f_{et} > 0.4 MPa (flexural tensile) (Note 4) (lowest of 5 results) (Tests G1, G2)
Wet/dry appraisal	J	✓	✓	✓	✓	✓	✓	3	Not required but see Note 2	Pass
Durability	K, L	✓	✓	✓	✓	✓	✓	1 spray (K1)or 2 drip (L1)	Not required but see Note 2	As required by NZS 4297 or NZS 4299
Shrinkage	H			✓	✓	✓	✓	1 if multiple mixes being tried 2 if one mix only being tried	Not required but see Note 2	≤0.05% for rammed earth ≤1.0% for mortar with lime/cement ≤2.0% for mortar without cement ≤2.0% for cob
On-site moisture handful drop test	I				✓			1 for each test or batch	1 per batch	Appendix G
Whole brick drop test	F		✓	✓			See note 9	2	2 samples of 5 individuals for every 5000 bricks or part thereof (Notes 2, and 3)	Pass
		✓				✓		2	2 samples of 5 individuals for every 2500 bricks or part thereof (Notes 2, and 3)	Pass

Layering test	P	✓						1 sample of 5 bricks for every 2500 bricks or part thereof	1 sample of 3 bricks for every 2500 bricks or part thereof	Layering present in no more than 1 brick per sample
Density (Note 12)	M	✓	✓	✓	✓	✓		3 samples		
Flexural Bond (Note 13)	N	✓	✓				✓	1 sample of 5 mortared brick "couplets"	a)1 sample of 3 couplets b)2nd sample of 5 couplets if (a) fails	f_{eb} > 0.015 MPa adobe f_{eb} > 0.025 MPa pressed earth
Clay content	A, B						✓		5 samples for every 5000 bricks or part thereof (Notes 2 and 3)	

NOTE –

(1) One of the four nominated tests shall be used except as provided for in Note 3.
(2) Plus extra tests where there is any evidence of change of soil.
(3) If the sample passes the whole brick drop tests (Appendix F) during construction, compression and flexural tensile tests are not required during construction. Note that bricks that fail the drop test can pass the flexural tensile or compression test and so may be deemed to pass the drop test.
(4) The tabulated required results, f_{espl} (the least of the five individual results in the set) are for samples with height/thickness ratio of 2.0. For samples with other height/thickness ratios the required result, f_{espl}, shall be the tabulated value times $1.0/k_a$ where k_a, the aspect ratio factor, is determined in accordance with E2.3 in Appendix E.
(5) Refer to D3.3 in Appendix D for abnormal test results.
(6) For plants producing earth building materials from the same source or sources for a number of structures the test frequencies of 2.5.1.3 shall apply.
(7) For rammed earth or poured earth take one sample of five individuals every 50 m^3 of wall.
(8) For earth mortar the same composition as the bricks only the shrinkage test shall be required, otherwise all tests shall be as detailed.
(9) This test may be used to test mortar that has been cast and cured in samples the same size as the whole bricks being laid.
(10) These tests may be used to test cob that has been cast and cured in samples the same size as adobe bricks. Shrinkage is tested using the wet cob mix pushed into the shrinkage moulds.
(11) The cob shrinkage test result is not indicative if the shrinkage expected on site and the method of construction ensures that the effects of shrinkage on the completed wall are minimised.
(12) This density test is required where:
 (a) Lightweight adobe or cob is used;
 (b) The mass of the wall per square metre is critical, for example, internal brick veneer; or
 (c) The thermal performance of the building is to be determined.
(13) This flexural tensile bond test as described in Appendix N requires using mortared "couplets"(stack bonded piers two bricks high) :
 (a) Prior to construction where:
  (i) there is no history of similar materials used in the region
  (ii) required by the engineering designer (Results analysed in accordance with Appendix D)
 (b) During construction if the nominated monitoring person identifies the need for bond quality confirmation.
 Results of all individual tests shall be tabulated and f_{eb} determined in accordance with Section 4 for adobe and unstabilised earth bricks or Section 5 for stabilised or pressed earth bricks with mortars including lime/cement.

2.6 Materials testing for special grade earth wall construction

2.6.1 *Tests before commencing construction*

2.6.1.1

The level of testing for special grade materials for use in buildings to be designed using the provisions of NZS 4297 shall be not less than that required by 2.5. Where design material strengths to be relied upon are in excess of the values in Table 2.1 of NZS 4297 then those design strengths shall be determined in accordance with Appendix D, where appropriate, from the results of tests conducted in accordance with Appendix clauses E, F, G, H, I, J, K, L, M, N, O, and P.

C2.6.1.1

The design of a building can require higher standards of strength or durability than the minimums set by this standard. Where this is the case, a more stringent testing regime than that outlined in 2.5.1 could be required. Other tests might be called for at the discretion of the designer although such testing is outside the scope of this standard.

2.6.1.2

Samples shall be dried to a moisture content of between 3.0% and 5.0% prior to being tested. Drying of samples shall be carried out at temperatures below 70°C.

Samples shall be representative of both the manufacturing techniques and curing conditions of the construction.

C2.6.1.2

This moisture content is assumed in a cured air-dried sample 28 days old.

2.6.2 *Target strength for quality control of special grade earth materials*

2.6.2.1

The target average strength values for special grade earth construction shall be:

(a) Compressive strength 1.9 f_e; or
(b) Flexural tensile strength 2.1 f_{et}.

Where the average strength of the last five samples (running average) is less than 90% of the target average strength, then action shall be taken to investigate and rectify deficiencies, and to return the strength of the subsequently built wall materials to not less than the target strength.

2.6.2.2

Average strengths shall be derived from test results in accordance with Appendix D.

C2.6.2.2

The running average of five samples means that the new test value for the latest sample is added to the results of the most recent four samples and the average determined.

The average value target strength must be much higher than the design value because design strengths are based on the characteristic strength for the lowest 5% of all the tests.

2.6.3 *Quality control tests during construction*

The procedures of 2.5.2 shall be followed, but the test results obtained shall meet the values required to confirm the characteristic strengths determined by 2.6.1 and 2.6.2.

2.6.4 *Non-compliance*

The whole-of-the-wall construction represented by the sample shall be deemed not to comply if the test strength of that sample is less than 0.5 of the target strength, or if the sample is one of two consecutive samples where the average is less than 0.65 of the target strength.

2.7 Initial preparation

2.7.1 *General*

2.7.1.1

Rubbish and organic matter, including topsoil, shall be removed from the area to be covered by the structure.

2.7.1.2

All earth walls shall be built on completed foundations constructed in accordance with NZS 4297 or NZS 4299.

2.7.1.3

The damp-proof course required by NZS 4297 or NZS 4299, as appropriate, shall be in place prior to commencing construction of a wall.

C2.7.1.3

It is important that an earth wall be protected from rising ground moisture. Attention will need to be given to site drainage.

2.7.2 *Concrete base*

Concrete footings, foundations, and floors shall be constructed in conformity with NZS 3109.

2.7.3 *Starter bars*

2.7.3.1

Where reinforcement is to be incorporated within earth walls, starter bars shall be set into concrete base work. The size, spacing, and embedment of starter bars shall comply with clause 5.5 in NZS 4299 or be subject to SED in accordance with NZS 4297. Connecting starter bars to other steel reinforcement shall be in accordance with 2.8.4.

2.7.3.2

Reinforcement shall be fixed with the following tolerances except that cover may not be reduced below that required by 2.8.7:

(a) Across the thickness of a wall ±20 mm;
(b) Along the length of a wall for vertical bars ±50 mm;
(c) Up the height of a wall for horizontal bars ±50 mm;
(d) In a column or pier ±20 mm.

2.8 Reinforcement details

2.8.1 *General*

2.8.1.1

In buildings subject to SED, reinforcement shall be as specified by the requirements of NZS 4297. Steel reinforcing bars and mesh shall conform to AS/NZS 4671.

C2.8.1.1

While this standard covers the use of steel reinforcement and polypropylene biaxial and triaxial geogrid, it is not the intention of this standard to restrict the use of other reinforcement materials such as barbed wire, bamboo, glass fibre, Kevlar, and others either within the wall or as part of a surface coating, provided they have satisfactory strength, stiffness, bond, and durability. The use of such materials is outside the scope of this standard.

2.8.1.2

In buildings not requiring SED, which comply with NZS 4299, reinforcement shall be as required by NZS 4299.

2.8.1.3

All steel reinforcement shall be detailed, bent, and placed in accordance with NZS 3109 or NZS 3124, except where modified by this standard or by SED in accordance with NZS 4297. Cover and corrosion protection shall be provided in accordance with 2.8.7.

2.8.1.4

The radial secant stiffness of triaxial geogrid shall be determined in accordance with BS EN ISO 10319:2015 and with reference the European EOTA Technical Report TR41.

The radial secant stiffness at 0.5% strain for grade 30 triaxial geogrid shall be 390 kN/m.

The radial secant stiffness at 2% strain for grade 30 triaxial geogrid shall be 290 kN/m.

The radial secant stiffness at 0.5% strain for Grade 40 triaxial geogrid shall be 480 kN/m.

The radial secant stiffness at 2% strain for grade 40 triaxial geogrid shall be 360 kN/m.

2.8.2 *Vertical reinforcement*

2.8.2.1

Vertical bars shall be spliced to starter bars in accordance with 2.8.4.

2.8.2.2

Vertical bars shall be maintained in their correct position as work progresses.

2.8.2.3

Long bars projecting above the top of the wall shall be held to maintain the bars in their correct position and shall be braced firmly against wind or other movement.

2.8.2.4

Unless otherwise required by SED, each vertical bar shall be positioned in the centre of its cell or in the middle of the cavity in grouted-cavity construction.

2.8.2.5

Where a services conduit and a vertical reinforcing bar are located in the same cavity, horizontal reinforcing shall be in contact with the vertical reinforcing but not with the conduit.

2.8.2.6

Vertical deformed steel reinforcing in rammed earth shall be enclosed in plastic sleeves.

D12 and HD12 bar sleeves shall be a maximum of 16 mm in internal diameter. D16 and HD16 bar sleeves shall be a maximum of 21 mm in internal diameter.

C2.8.2.6

Sleeves may be pipe or conduit, low-density polyethylene to NZS 7601, or medium-duty uPVC to AS/NZS 2053.1.

Observation has shown that vertical reinforcement in rammed earth can sometimes induce a vertical crack but plastic ducting, even if of slightly larger diameter, does not. The reason for this is obscure.

Inserting the vertical reinforcing within a plastic duct reduces the risk of cracking occurring at that location and also reduces the risk of horizontal shrinkage cracks from rammed earth hanging up on vertical reinforcing. It also allows the vertical rod to be used for post-tensioning of the wall.

2.8.3 *Horizontal reinforcement*

2.8.3.1

The maximum diameter of horizontal steel reinforcement shall be 12 mm.

2.8.3.2

The use of polypropylene biaxial or triaxial geogrid used for horizontal reinforcement in mortar courses shall comply with 2.8.1.4.

> ***C2.8.3.2***
>
> *Polypropylene biaxial or triaxial geogrid is recommended for horizontal reinforcement.*

2.8.3.3

Each horizontal reinforcing element shall be positioned centrally in the wall.

2.8.3.4

Mortar joint reinforcement shall be fully embedded in mortar and shall comply with cover requirements.

2.8.3.5

Geogrid shall be positioned with proprietary bodkins or purpose-made steel rods that are woven through the geogrid and bear against the vertical reinforcement. See Figure 6.5 Horizontal reinforcement of earth walls in NZS 4299:2020.

2.8.4 *Splices in steel reinforcement*

2.8.4.1

Splices in reinforcement embedded in earth shall be mechanical connections that comply with 2.8.4.3 or be 50 mm lap welds carried out in accordance with NZS 3101 clause 8.5.

2.8.4.2

No lap splices shall be permitted in cells filled with earth-based grout or mortar.

Laps in cement-lime-sand or cement-aggregate grouted cells shall only be permitted by SED, and only where the least distance between the surface of a bar and the edge of a cell is greater than four times the bar diameter.

2.8.4.3

Reinforcing bars manufactured with a hot-rolled screw thread may be spliced using proprietary connectors that comply with the requirements of NZS 3101, clause 8.7.5. Such connectors shall comply with the cover requirements of 2.8.7.

2.8.5 *Connecting geogrid reinforcing*

2.8.5.1

Splices in geogrid reinforcing shall be formed by overlapping the geogrid by 300 mm at a vertical reinforcing rod and threading a 6 mm diameter by 200 mm long high-density polyethylene (HDPE) or galvanised steel rod through the geogrid on both sides of the reinforcing rod.

2.8.5.2

At the ends of reinforced earth walls the geogrid shall be anchored to the vertical reinforcing rod with a 6 mm diameter by 200 mm long HDPE or galvanised steel rod threaded through the geogrid on the outside edge of the reinforcing rod.

2.8.6 *Tolerances*

2.8.6.1

Earth walls shall be built to the specified dimensions within the tolerances given in Table 2.2.

> ***C2.8.6.1***
>
> *Earth walls such as cob or in-situ adobe can have a handmade character where straight or accurate lines may not be wanted or needed, so tolerances become an engineering parameter, as well as a practical and/or aesthetic parameter.*

Designers are free to specify tighter tolerances than those given here if they wish, although different earth building techniques and level of skill of the builders may pose different levels of difficulties in achieving these.

Cob is often handmade and can lend itself to more sculptural forms, so tolerances are often set at the looser end of all the techniques. Adobe bricks, like cob, may be hand made with variable dimensions, but may be able to be laid with tighter tolerances than cob, but that can depend on the bricks that are available.

Rammed earth and poured earth may aim for accurate construction industry tolerances, but pressure imposed on the formwork usually results in some deviation and +/- 15 mm on a 2.4 m vertical panel and a bulge of up to 10-15 mm over 3 m wide panel may pose a practical upper limit.

Pressed earth brickwork accuracy may depend to some degree on brick variation during manufacture, but the aim could be a upper limit similar to rammed earth. Pressed earth bricks sometimes have their edges rounded in order to look more like adobe and given similar tolerances for aesthetic reasons.

Table 2.2 Tolerances in earth construction

Item	Tolerance
Horizontal position of any earth building element specified or shown in plan at its base or at each storey level	±30 mm
Deviation within a storey from a vertical line through the base of the member	±25 mm per 3 m of height or ±0.1 times thickness of walls, whichever is less
Deviation from vertical in total height of building (from base)	±25 mm
Relative displacement between load-bearing walls in adjacent storeys intended to be in vertical alignment	±30 mm
Deviation (bow) from line in plan in any length up to 10 m	Single curvature ±30 mm Multiple curvature: (see Note 1)
Deviation from vertical at surface against which joinery is to be fitted	±10 mm
Deviation from specified thickness of bed joint	±30 mm average in any 3 m length
Deviation from design wall thickness	–10 mm, +20 mm, or 5%, whichever is larger

NOTE –

(1) For walls with multiple curvature in plan, the permitted displacement of any point over a length of 10 m shall be such that all points on the surface of a wall lie within two lines in plan 50 mm apart, parallel with the nominal centreline of the wall.

(2) Tighter tolerances than these may be required where statutory requirements are to be met, such as at property boundaries.

2.8.6.2 Reinforcement placing tolerances

Reinforcement shall be placed in the specified positions within the tolerances given in 2.7.3.

2.8.7 *Cover and corrosion protection*

2.8.7.1

Steel reinforcement of mortar, earth, and grout, treated as a homogeneous material, shall have a cover of not less than:

(a) 40 mm for surfaces not exposed to the weather; or

(b) 100 mm for surfaces exposed to the weather.

For rammed earth the minimum earth cover provided for reinforcing bars shall be 100 mm for bars that are ungrouted or enclosed within plastic ducts.

2.8.7.2

Polypropylene biaxial or triaxial geogrid horizontal mesh shall have a minimum cover of 40 mm in any location.

2.8.7.3

In reinforced brick construction all reinforcing bars shall be maintained at least 25 mm from earth surfaces in core holes at all points, and this space shall be filled solid with grout or mortar as work proceeds.

2.8.7.4

Steel reinforcing and embedded structural hardware, except bond beam dowels, shall be hot-dip galvanised or painted with zinc rich or bituminous paint unless it has a covering of lime/cement/sand grout not less than 25 mm thick.

C2.8.7.4

In aggressive environments, such as coastal, volcanic, or industrial areas, particular attention shall be given to providing a moisture-resistant dense earth and, where appropriate, the covers specified in 2.8.7.1 and 2.8.7.3 may be increased or special surface protection can be provided to give enhanced life expectancy.

2.9 Quality control

Systems of batching, recording, and evaluation shall be used to ensure that the earth, water, and admixture that go into walls or walling units are consistent, uncontaminated, and able to produce performance results as required by this standard.

2.10 Bracing during construction

2.10.1

Where structural stability cannot be assured during construction, temporary external bracing shall be installed that will prevent movement that would cause cracking or collapse. The design of such bracing is outside the scope of this standard.

2.10.2

The sequence of construction of the earth walls of a building shall take account of the following:

(a) An earth wall does not reach its full strength until it is fully cured. The capacity of earth walls to withstand forces such as wind or impact while under construction shall be considered;
(b) In the case of brick walls, work shall not progress vertically beyond the capacity of the uncured mortar to bear the weight;
(c) Every use should be made of the self-bracing effect of building corners and intersecting walls progressively; and
(d) High gable end walls are particularly vulnerable. Consideration shall be given to building high gable end walls once roof framing is in place and able to provide some buttressing opportunity.

C2.10.2

Earth walls are extremely heavy and represent considerable danger to human life if unrestrained in a situation that allows them to collapse onto people.

2.11 Cold weather construction

Work shall stop when the air temperature is less than 2°C.

Where the air temperature is likely to be less than 2ºC at any time during construction, appropriate protection shall be taken to prevent frost damage to the stored earth building materials on site and those already incorporated into the structure.

C2.11

A longer drying time can lengthen the time it takes for a wall to gain its full cured strength. In the case of brickwork, the longer time for mortar to set can decrease the number of courses that can be laid in a day.

Although freeze-thaw cycles can have a damaging effect on earth building materials, it is only in the most severe high-altitude environments in New Zealand that this could be a problem. Generally, the eaves protection and the warmth of a completed building will protect it.

During construction, materials stored in the open, particularly partly dried adobe, can be damaged by a single hard frost.

2.12 Hot weather construction

Excessive cracking can occur in bricks or walls that are allowed to dry too quickly, particularly if windy. Some shading or covering could be required in hot weather. In earth brick walls, jointing should be cleaned up progressively. Lime-cement based mortar shall not be reconstituted.

2.13 Protection during construction

Where structural damage to walls from rain or pooling water is imminent during construction, appropriate covering and drainage shall be provided.

2.14 Control joints

2.14.1

Every earth wall except for adobe bricks, cob, and constructed with mortar that does not contain cement, shall have control joints at spacings that will ensure that any cracking which occurs will not cause the wall to fail strength or serviceability requirements. Control joints are optional in adobe or cob construction that are not cement or lime stabilised.

For detail on the location and construction of control joints see NZS 4299 section 11.

2.15 Surface finish

A surface finish exposed to the exterior environment, and which tends to trap or hold water so that it affects the durability of the material, is not permitted. Refer to section 8.

Many factors affect the surface finish and weathering of an earth wall, and different earth building techniques give a wide range of surface finishes and appearances. Designers should familiarise themselves with the different finishes that can be obtained when choosing a particular earth building technique or when specifying a particular surface finish.

See also 3.8 and C3.8.1, 4.10 and 6.8 and Appendix G Maintenance schedule for earth walls.

2.16 Bond beams

Bond beams, where required by a design in accordance with NZS 4297 or NZS 4299, shall be constructed in accordance with the appropriate materials and construction standards as noted below:

(a) For reinforced concrete, NZS 3109;
(b) For reinforced masonry, NZS 4210.

2.17 Timber diaphragms and timber bond beams

Timber diaphragms or bond beams, where required by a design in accordance with NZS 4297, shall be constructed in accordance with NZS 3603 or NZS 4299.

3 REQUIREMENTS ADDITIONAL TO SECTION 2 FOR RAMMED EARTH

C3 GENERAL

Rammed earth can be used without stabilisation, but it is more usual to include Portland cement to enhance the structural and durability qualities of walls. Earths used in rammed earth walls usually contain a smaller ratio of clays than those used for adobe or cob.

Unlike bricks which can be evaluated, accepted, or rejected, before a wall is in place, the full characteristics and effect of rammed-earth work can only be evaluated once formwork is removed. The implications of requiring demolition of a wall or walls are considerable. New builders may well be advised to consider constructing test panels before embarking on a building. Note also the requirement for sleeving of vertical reinforcing in rammed earth in 2.8.2.5.

3.1 Moisture content

3.1.1

The moisture content of the rammed-earth mix just prior to compaction shall be within 3% of the optimum moisture content for maximum dry-density compaction as determined from NZS 4402.4.1.1. This 3% band, either side of optimum moisture content, may be widened where tests in accordance with 3.2 have been carried out showing that a wider range of moisture content can be used and a wall built giving satisfactory performance and complying in all other aspects with this standard. In any event, the range shall not be more than 4% dry of optimum or 6% wet of optimum.

3.1.2

An alternative suitable on-site test of moisture content for each batch is described in Appendix I.

3.2 Compaction

3.2.1

When earth materials are compacted in walls, they shall be compacted to 98% of the maximum dry density as determined from NZS 4402.4.1.1.

3.2.2

Acceptable compaction shall be deemed to have been achieved when the surface ‘rings’, meaning when a 6.5 kg hand rammer rings when dropped 300 mm on to the wall material, which is within the moisture content limits specified in 3.1. This is the minimum level of compaction for every part of every wall and it is quite acceptable for some areas to be compacted to a greater degree.

C3.2.1

Differing methods of compaction can be employed so long as the required level of compaction is achieved. Differing methods of compaction can be used within the same panel of rammed earth. Finished walls can exhibit the characteristic wavy horizontal ramming lines and varying degrees of exposed aggregate over the wall face. Ramming lines can undulate and exhibit varying levels of compaction. For example, in one panel machine ramming, in part, and hand ramming, in part, may be employed. Typically, machine ramming would be used where possible and hand ramming employed in areas of difficult access. There is nothing in this standard to prevent a complete project being hand rammed, so long as the required level of compaction is achieved. Compaction would normally be carried out on layers with a loose thickness of 100 to 150 mm.

Regardless of the uncompacted course depth and the compaction equipment used, the fundamental requirement is that the compacted layer achieves the specified minimum level of compaction and the minimum density throughout the finished compacted course.

3.3 Tolerances

Tolerances for the placement and alignment of rammed earth walls are set out in 2.8.6.1 and Table 2.2.

C3.3

It should be noted that the forces involved in ramming walls are considerable. Care needs to be taken both in setting up formwork and in the strength and stiffness of the formwork itself to ensure accurate wall placement and a surface finish that is acceptable. Varying surface texture from varying degrees of ramming is quite acceptable.

3.4 Control joints

Control joints shall be provided in accordance with 2.14.

3.5 Construction joints

3.5.1 *Cold joints*

There shall be a structural connection across a cold joint. This shall be provided by roughening of the old surface to an amplitude of 5 mm (to provide a mechanical key), cleaning the old surface by removing all stale mix and wetting of the old to best bond the new to the old.

C3.5.1

Chemical keying compounds may also be used to improve bond but their use is outside the scope of this standard.

3.5.2 *Fresh mix*

3.5.2.1

The moisture content at time of placement shall be within the tolerances specified under 3.1 of this standard.

3.5.2.2

For cement stabilised rammed earth, all of a mixed batch shall be placed and rammed within 45 minutes of the cement first coming in contact with water or damp earth except as provided by 3.5.3.

C3.5.2

With cement stabilised rammed earth, the timing from start of addition of water or damp earth to the time of finishing compaction is critical.

3.5.3 *Stale mix*

Stale mix, being that which is older than 45 minutes from initial wetting, may not be used neat in a wall but may be used as up to 30% of the proportion of material in a new fresh mix. A fresh mix can comprise up to 30% stale mix and 70% fresh mix, so long as fresh cement is added to this new mix as if there was no cement in the stale mix. All properties of the wall made with this mix containing part stale mix shall fully conform in all regards to this standard as if there were no stale mix present.

3.6 Cracks

3.6.1

Cracks over 3 mm in width and appearing on both sides of a panel, except at intended control joint locations, are not acceptable. Cracks less than 3 mm in width and on both sides of a panel are minor. Any width of crack at intended control joint locations is acceptable provided the requirements of 2.14.3, 2.14.4, and 2.14.5 are met.

C3.6.1

Cracks can occur in rammed earth walls for a variety of reasons. These include insufficient or inadequate control joints, inadequate construction practices, or localised shrinkage. Many such cracks are of no structural consequence. Minor nature cracks may be filled or patched to meet the aesthetic requirements of the project.

3.7 Repair of rammed earth walls

3.7.1 *Cosmetic repair of cracks in cement stabilised rammed earth*

For cosmetic repair, small cracks and holes shall be carefully raked open in a V-shape to a minimum of 6 mm wide and 10 mm deep, and all loose material shall be removed. A masonry bonding agent shall be applied with a small brush, being careful not to let it run down the wall. While still damp, the crack shall be filled with the same recipe ingredients used to make the wall. The ingredients shall be sieved to an appropriate size to fit in the crack. The bonding agent may not always be required.

3.7.2 *Weather proofing cracks in cement stabilised rammed earth*

For weather proofing, small cracks in cement stabilised walls shall be filled with an exterior UV-resistant sealant that has a good colour match. The crack shall be carefully raked open to enable the correct height-to-width ratio of the sealant chosen. All loose material shall be removed, and the area primed with a primer compatible with the sealant and designed for masonry. A bond breaker shall be applied to the bottom of the crack, so only the sides stick, as specified in most construction scenarios. The sealant shall be gunned into the crack and the finish tidied.

C3.7.2

It is recommended to try a sample area to check the result first. This job is best done by someone experienced in using sealants. Any excess stuck to the wall can be unsightly and requires mechanical removal. For repair of unstabilised rammed earth walls, repair as for cob walls with new material that matches the original material tightly tamped into place.

3.8 Surface finish

3.8.1

Many factors, including mix characteristics, and/or ramming strength and consistency, may affect the surface finish.

C3.8.1 Surface finish

The surface finish can best be described as the texture and colour of a rammed earth wall. It is a function of many variables. The surface finish can be classified according to its physical characteristics, such as roughness, smoothness, pebbliness, flatness, and such. It may be described in terms of dimensional accuracy to accord with drawing plans and other tolerances in terms of colour and consistency of colour. Texture can be smooth, rough, or variable. Variations can be accidental or intentional.

Where surface appearance is important, sample panels are recommended.

For plastering or surface coatings refer to section 8.

4 REQUIREMENTS ADDITIONAL TO SECTION 2 FOR ADOBE BRICKS

4.1 General

Bricks and earth mortar may be laid up as structural, load bearing walls.

C4.1 General

Variations include:

(a) Low density adobe (structural light adobe);

(b) The stabilisation of adobe with such admixtures as cement, and hydrated lime;

(c) The use of surface sealants to enhance the resistance to erosion and replace much of the cyclic maintenance that would traditionally have been needed; and

(d) The use of adobe as a free-standing or infill material that is not necessarily performing a significant structural function. Furniture is included in this category.

Solid units

Adobe bricks can be manufactured in a wide range of sizes and dimensional proportions. The limiting factors include:

(e) The size and hence weight that can be safely and efficiently handled;

(f) The thickness of walls to be built. While walls can consist of more than one brick to make up the thickness, it is more common to use a single brick;

(g) The need to maintain bonding at corners. One alternative is to produce a number of longer bricks for this purpose while working with smaller bricks in straight overlapping bond walls;

(h) Excessive shrinkage cracking can occur with some earths in anything but the smaller size bricks. Extra fibre (straw or wood shavings) and/or sharp coarse sand or fine gravel may be added to a mix to help reduce shrinkage cracking.

Preferred sizes

There are no preferred nominal brick sizes but in New Zealand external walls need to be minimum of 280 mm (nominal) thick for structural performance.

Consistency in brick thickness has an influence on the thickness of bed joint and hence the amount of mortar required. In a commercial environment the amount of dimensional variation allowed should be nominated. Provided that bricks and mortar meet the test requirements of this standard, variations in brick size make little effect on strength or durability.

4.2 Conditions of brick manufacture

Earth for adobe bricks should be soaked for at least 12 hours before moulding, unless it can be established through trials that particular earth will make a serviceable brick without prior earth soaking.

Adobe bricks can be moulded in one of two ways:

(a) By placing mud into a mould that is removed immediately; or

(b) By placing mud into moulds and waiting until the mixture dries and the brick shrinks sufficiently to remove the mould.

C4.2

Both methods depend on air drying rather than sun baking. Excessive exposure to wind can accelerate surface drying and cause cracking during initial curing.

Following initial drying, the bricks are turned on their side, scraped and allowed to cure until, when tapped, they produce a clear ring. They are then ready for laying. Depending on the size of the brick and the weather, curing takes from one week to several months, usually at least four weeks.

4.3 Cored units

Cores for vertical reinforcement or services may be drilled or moulded. Such holes shall be a maximum of one-third of the brick width and be centred on the centre line of the wall.

All holes are to be filled with mortar or grout as work proceeds. See also 2.8.4 and 2.8.7.

C4.3

The bricks may be moulded with holes to provide passage for services or reinforcement. However, this could increase the risk of cracking during drying. It is easy to drill holes during construction.

4.4 Straw or other natural fibres

Straw or other natural fibres, where used, are to be cut into lengths not exceeding one half the finished wall thickness and added to the mix evenly.

C4.4

Straw or fibres are generally added to an adobe mix to help control cracking and help the uniformity with which adobe dries. It is unusual to add both cement and straw to earth mixtures.

4.5 Laying rate

There shall be a maximum of four courses of bricks or 60 mm of total mortar thickness laid per day.

4.6 Bonding pattern

The bricks are to be laid in an overlapping bond pattern where subsequent layers are overlapped by between 25% and 75% of the brick length. The minimum overlap shall occur at right angled corners including both ‘tee’ and ‘ell’ intersections.

C4.6

English, Flemish, garden wall, and stretcher bond patterns are acceptable. Longer bricks can be moulded to maintain up to a half bond around corners. Where a wall meets another, the required overlap can be achieved by letting every second brick halfway into the abutting wall.

4.7 Mortar joints

4.7.1 *Soaking*

All brick surfaces about to come into contact with mortar shall be moistened before laying by spraying or dipping.

C4.7.1

Wetting improves bond and mortar workability.

4.7.2 *Thickness variation*

The maximum thickness of a mortar course is to be determined by its ability to support the brick without excessive slump or bellying.

C4.7.2

Because of the method of manufacture, adobe bricks can vary as much as 10 to 15 mm in thickness. As such, mortar courses can be in the order of 15 to 35 mm thick to accommodate the variations. Depending on the dimensional accuracy of the units, too thin a mortar course can result in the bricks bedding on each other. However, thicker mortar joints will cause the wall to subside more during curing.

4.7.3 *Shrinkage*

4.7.3.1

Vertical settlement due to mortar shrinkage shall be provided for when laying up the wall by applying the provisions of this clause. In fixing ties between brickwork and items such as posts or joinery frames, all brickwork below the level shall first be allowed to settle.

4.7.3.2

Fittings, frames and vertical reinforcement embedded in the wall shall be detailed to allow for shrinkage to ensure that the shrinkage can occur unrestrained. See NZS 4299.

4.7.3.3

Perpends shall be of sufficient thickness to maintain the bond between bricks within a course.

4.7.3.4

All mortar joints and courses shall be flush or tooled no deeper than 5 mm, with no voids.

> ***C4.7.3.4***
>
> *Care should also be taken when brickwork runs across a change in foundation level.*
>
> *If vertical shrinkage is restrained by other parts of the structure, then cracking due to 'hanging up' is likely to result.*

4.8 Flexural tensile bond

Flexural tensile bond strength (adhering bricks together between courses) shall be determined using the bond wrench test as specified in Appendix N if required.

Flexural tensile bond is an indicator that wall integrity has been achieved by good quality brick laying. A set of bond tests should be carried out if required for quality validation in the cases described in 4.8.1 and 4.8.2.

If an earth building designed in accordance with NZS 4297 relies on flexural bond for structural strength it shall meet the requirements specified in 4.8.3.

4.8.1 *Quality validation before construction*

Quality validation is required if there is no pre-existing regional experience with the brick materials and the mortar used.

A bond wrench test result indicates adequate quality laying procedures if a minimum value according to Table 2.1 is achieved by five test specimens - mortared "couplets" (stack bonded piers two bricks high) dried in accordance with Appendix N under ventilated cover.

4.8.2 *Quality validation during construction*

Quality validation is also required if laying procedures observed during construction appear to be inadequate to the nominated construction monitoring person. This may be evident by laid bricks that have little or no mortar bond.

A bond test indicates adequate quality laying procedures if a minimum value of 0.02 MPa is achieved by testing three mortared couplet specimens after 21 days of dry weather. If this is unsuccessful a full test series of five specimens shall be undertaken in accordance with Appendix N.

> ***C4.8.2***
>
> *Little or no bond is indicated if bricks are accidentally knocked out of alignment by minor construction loads or if a brick laid appears to have no bond when gently lifted after three or more days' drying. It is recommended that eight brick couplets are constructed in case the initial test of three specimens at 21 days fails.*

4.8.3 *Bond strength validation*

If engineering design of walls in accordance with NZS 4297 requires tensile strength for out-of-plane performance, then a minimum of 0.035 MPa should be achieved for five specimens - mortared couplets (stack bonded piers two bricks high) for the NZS 4297 characteristic design strength of 0.02 MPa. If higher design bond strengths are required by engineering designers then the tests should have the analytical procedure specified in Appendix D applied to the results.

C4.8.3

Generally, vertically reinforced earth walls have little reliance on the flexural tensile bond for mortared earth brick construction. In some cases, a designer may require the bond strength to be structurally available.

The minimum of 0.35 MPa is a simplified value for determining characteristic design strength and assumes a reasonably consistent set of five results with maximum strength not more than 2.5 times the minimum and coefficient of variation of less than 0.33. Appendix D would take precedence in all cases and provides a rigorous procedure for analysis of characteristic design strength for samples with more or less variability.

4.9 Control joints

Control joints shall be provided as required by 2.14.

4.10 Finishing

Low-density adobe or cob, with a density from 800 to 1400 kg/m^3, shall be coated with hydrated lime plaster in accordance with section 8. Heavy-weight adobe walls may be finished with either earth or lime surface coatings in accordance with section 8.

4.11 Repair of adobe walls

4.11.1 *Repair of holes and damaged mortar joints in adobe walls*

For small areas of damage in adobe walls of any density that are not stabilised with cement, a patching mix of a similar composition to the original mortar mix shall be used. This typically is a mix of one part clay soil and two parts coarse sand, with optional addition of finely chopped straw fibre.

The hole or damaged mortar joint shall be brushed out to remove any lose material, and then thoroughly wetted with water to activate the stickiness of the original material. Clay slip shall be rubbed into the activated surface immediately before adding new material. The hole shall then be filled by hand-rubbing in some patching mix with enough pressure to get the aggregate to key into the damp surface, and then filling the rest of the hole to the shape of the original wall, either by hand or with a small trowel.

The repair shall be left to dry thoroughly before being finished off with the original wall finish to be concealed and blended in.

4.11.2 *Repair of cracks in adobe walls*

Small cracks in adobe walls of any density that are not stabilized with cement shall be repaired with a patching mix of a similar composition to the original mortar mix used, This typically is a mix of one part clay soil and two parts coarse sand, with optional addition of finely chopped straw fibre.

The crack shall be scraped out a bit deeper in a V shape using a steel blade and brushed out to remove any lose material. It shall then be thoroughly wetted with water to activate the stickiness of the original material, and clay slip rubbed into the activated surface immediately before adding new material. It shall then be filled by hand-rubbing in some patching mix with enough pressure to get the aggregate to key into the damp surface, and then filling the rest of the crack to the shape of the original wall, either by hand or with a small trowel.

The crack repair shall be left to dry thoroughly before it can be finished off with the original wall finish to be concealed and blended in.

5 REQUIREMENTS ADDITIONAL TO SECTION 2 FOR PRESSED BRICKS

5.1 General

Testing in accordance with Appendix J of soil from a particular site shall verify that the earth mixture is suitable to be used, with or without cement, hydrated lime, or cement and hydrated lime as a stabiliser.

C5.1

This standard acknowledges that damp earth may be compressed into regular blocks for use, once cured, as building bricks. Careful soil selection is therefore necessary. It is common practice that cement is used as a stabiliser in pressed bricks.

Pressed earth bricks made from material that is not thoroughly mixed can result in unevenly bonded planes that can lead to failure. See 2.3.11 and Appendix P.

Previous use of specific materials may be used to indicate the suitability of soil from a particular site.

5.2 Conditions of brick manufacture

5.2.1

Bricks shall be fully cured before testing.

5.2.2

Cement or hydrated lime stabilised bricks shall be damp cured in accordance with 2.3.8.2 or 2.3.8.3 as appropriate.

C5.2.2

Equipment for compressing damp earth into bricks falls into two main categories:

(a) Manually operated devices which use a long lever arm to activate a ram within a compression chamber containing earth; and
(b) Hydraulically operated devices which replace the lever with hydraulic power to drive the compressing ram.

Satisfactory bricks can be made with either method and it should not be assumed that one is superior to the other in meeting the requirements of this standard.

To reduce the risk of damage, bricks should be fully cured before transporting away from the point of stacking following manufacture.

5.3 Cored units

The bricks may be moulded or drilled with holes to provide passage for vertical reinforcement or services. Cores for vertical reinforcement or services shall be a maximum of one-third of the brick width and centred on the centre line of the wall. Holes shall be filled with grout or mortar as installation proceeds. See also 2.8.4 and 2.8.7.

C5.3

Because of the process applied to the manufacture of pressed bricks there is a consequent limitation to the flexibility of production. This means that cored pressed bricks might not be generally available.

Holes to facilitate installation of services may be drilled on site. On-site drilling of holes can be preferred because it:

(a) Reduces potential breakage of bricks if they are required to be transported; and
(b) Enables placement of holes more accurately to facilitate inevitable service position variations.

Generally, it is easier to make a hole in the brick when it is pressed, or soon after while it is still green, rather than try to drill a hole in a cured brick.

Although pressed bricks can be made in a variety of sizes, in practice the chamber size of available machines is a limiting factor. Other limiting factors to be considered include:

(a) The size and hence weight that can be safely and efficiently handled; and

(b) The thickness of walls to be built.

Consistency in brick size has an influence on the thickness of bed joint and hence the amount of mortar required. In a commercial environment the amount of dimensional variation allowed should be nominated. Provided that bricks and mortar meet the testing standards of this standard, variations in brick size have little effect on strength or durability.

5.4 Grout spaces

Where spaces are created in the process of building in fixtures, draft strips, conduits, reinforcement bars, and the like, such spaces shall be completely filled with mortar.

5.5 Laying

5.5.1

Bricks are to be laid in an overlapping bond pattern.

C5.5.1

The constraints of the manufacturing process that apply to the production of pressed bricks generally do not enable longer bricks to be obtained to maintain a half bond around right angle corners. To maintain the half bond pattern a 'pig' brick needs to be installed adjacent to the overlapping corner brick (see Figure 5.1.) Alternatively, the larger gap can be filled with mortar and sculptured to produce an aesthetically appropriate finished result. For square bricks the details of Figure 5.2(c) and (d) may be used.

Refer to C4.8 for acceptable bond types.

5.5.2

Bricks shall be laid so that any compression planes that can have formed within the brick are perpendicular to the face of the wall.

C5.5.2

Compression planes are generally formed perpendicular to the direction of the ram in the brick press. In walls, the compression plane is normally horizontal.

5.5.3

All brick surfaces about to come into contact with mortar shall be moistened before laying by spraying or dipping.

C5.5.3

Wetting of bricks greatly enhances mortar bond strength and reduces excessive shrinkage and therefore cracking of mortar.

5.5.4

Where one wall meets another in a 'tee' intersection then every second brick shall be let at least 100 mm into the abutting wall (see Figure 5.2(a) and (c)). In the case of square bricks refer to Figure 5.2. Figure 5.2 applies to pressed brick only and is not to be used for adobes at corners or intersections where one and a half-length brick shall be used to get the required laps.

5.5.5

Reinforcing (steel bar or geogrid) shall be used in every second to fourth course with a maximum vertical spacing of 450 mm (see Figure 5.1 and Figure 5.2) to provide adequate bond strength.

C5.5.5

Laying patterns that provide details of reinforcing at corners and wall intersections are shown in Figure 5.1.

5.6 Mortar joints

5.6.1

The maximum thickness of a mortar course is to be determined by its ability to support the brick without excessive slump or bellying. Vertical settlement due to mortar shrinkage shall be provided for in laying up the wall. In fixing ties between brickwork and items such as posts or joinery frames, all brickwork below the level shall first be allowed to settle. Provision shall be made for differing settlement where brickwork runs across a change in floor level.

5.6.2

Perpend joints should be of sufficient thickness to maintain the bond between courses.

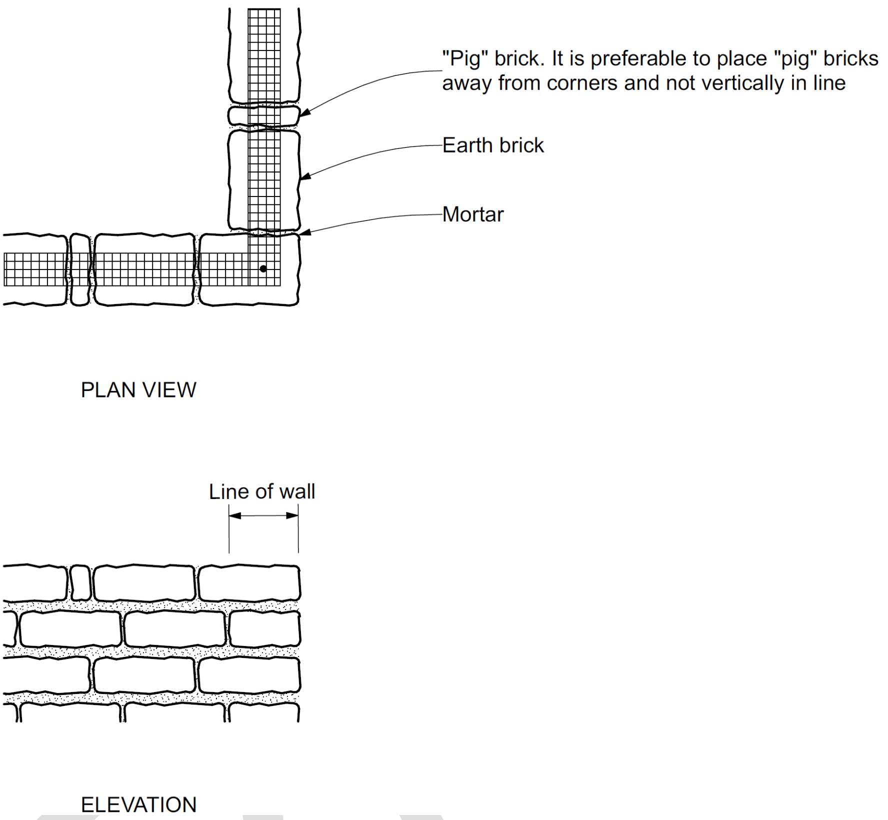


Figure 5.1 – Brick bond

5.6.3

Mortar courses shall be full with no internal voids.

5.6.4

Mortar courses may be raked only in accordance with 2.4.4.2 and 2.4.4.3.

5.6.5

Mortar shall be sufficiently thick to ensure that bricks do not bed in direct contact with one another.

C5.6.5

If earth type and moisture content are consistent, pressed bricks are usually of a consistent dimension in at least two directions. Variations in the dimension parallel to the direction of the ram movement can occur. This depends on the sophistication and accuracy of the measuring of both the earth in the chambers and pressure applied.

Depending on the dimensional accuracy of the units, too thin a mortar course can result in the bricks bedding on each other. However, thicker mortar joints will cause the wall to shrink more during curing.

When constructing an arch, the bricks may bed in contact with each other along the lower edge of the arch to prevent the arch shrinking when the former is removed.

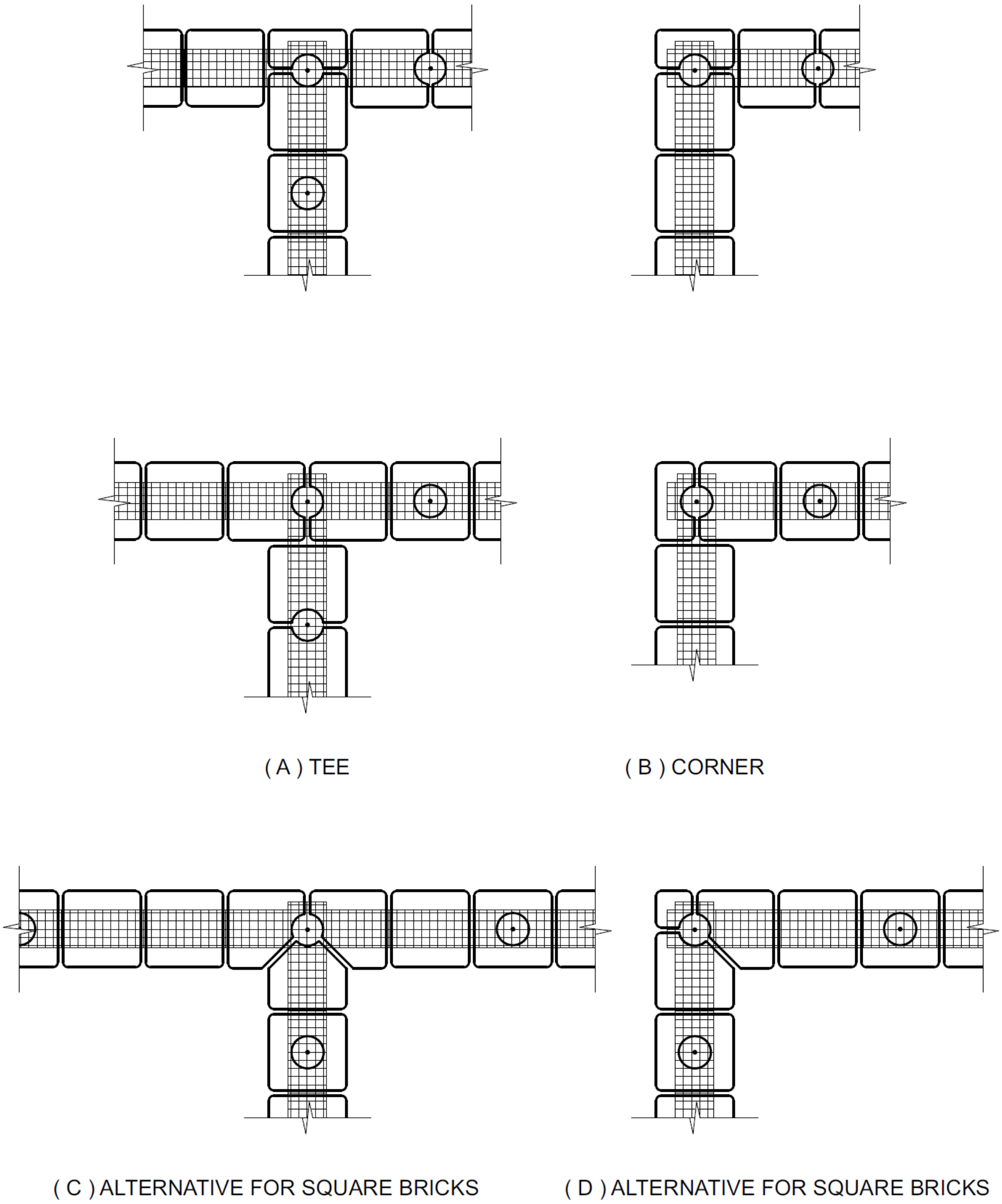


Figure 5.2 – Brick bond at ‘tee’ intersections and corners for pressed bricks only

5.7 Flexural tensile bond

Flexural tensile bond strength (adhering bricks or blocks together between courses) shall be determined using the bond wrench test as specified in Appendix N if required.

Flexural tensile bond is an indicator that wall integrity has been achieved by good quality brick laying. A set of bond tests should be carried out if required for quality validation in the cases described in 5.7.1 and 5.7.2.

If an earth building with engineered design to NZS 4297 relies on flexural bond for structural strength it shall meet the requirements specified in 5.7.3.

5.7.1 Quality validation before construction

Quality validation is required if there is no pre-existing regional experience with the brick materials and the mortar used.

A bond wrench test result indicates adequate quality laying procedures if a minimum value of 0.035 MPa is achieved by five test specimens - mortared couplets (stack bonded piers two bricks high) dried in accordance with Appendix N.

5.7.2 Quality validation during construction

Quality validation is also required if laying procedures observed during construction appear to be inadequate to the nominated construction monitoring person. This may be evident by laid bricks that have little or no mortar bond.

A bond test indicates adequate quality laying procedures if a minimum value of 0.035 MPa is achieved by testing three mortared couplet specimens after 21 days. If this is unsuccessful a full test series of five specimens shall be undertaken in accordance with Appendix N.

C5.7.2

Little or no bond is indicated if bricks are accidentally knocked out of alignment by minor construction loads or if a brick laid appears to have no bond when gently lifted after three or more days drying. It is recommended that eight brick couplets are constructed in case the initial test of 3 specimens at 21 days fails.

5.7.3 Bond strength validation

If engineering design of walls in accordance with NZS 4297 requires tensile strength for out-of-plane performance, then a minimum of 0.045 MPa should be achieved for five specimens - mortared couplets (stack bonded piers two bricks high) for the NZS 4297 characteristic design strength of 0.025 MPa. If higher design bond strengths are required by engineering designers, then the tests should have the analytical procedure specified in Appendix D applied to the results.

C5.7.3

Flexural tensile bond strength will be more critical in walls with narrower bricks. If a designer requires the bond strength to be structurally available, they should specify this.

The minimum of 0.045 MPa is a simplified value for determining characteristic design strength and assumes a reasonably consistent set of five results with maximum strength not more than 2.5 times the minimum and coefficient of variation of less than 0.33. Appendix D would take precedence in all cases and provides a rigorous procedure for analysis of characteristic design strength for samples with more or less variability.

5.8 Repair of pressed brick walls

5.8.1 Repair of holes and damaged mortar joints in pressed brick walls

For small areas of damage in pressed brick walls that are stabilised with cement and/or lime, a patching mix of a similar composition to the original mortar mix shall be used. For unstabilised pressed earth brick walls use a patching mix that matches the original brick material.

The hole or damaged mortar joint shall be brushed out to remove any loose material, and then dampened with water. Cement stabilised bricks shall be treated with a bonding agent for masonry. While still damp, the area shall be firmly packed out with new material that matches the original.

5.8.2 Repair of cracks in pressed brick walls

If there are cracked bricks, these shall be replaced with intact bricks.

C 5.8.2

If necessary, such as in locations where there are reinforcing rods within the wall or it is not feasible to remove whole bricks, cracked bricks may be raked out to one third of the wall thickness and replaced with intact brick slips on each side of the wall that are well mortared in with matching mortar.

6 REQUIREMENTS ADDITIONAL TO SECTION 2 FOR COB

6.1 General

This section applies to both low-density and heavy cob. This section does not cover stabilised cob mixes that use admixtures, such as cement and hydrated lime.

C6.1 General

Cob may be laid up as structural, loadbearing walls or as infill walls. It may be combined with unstabilised mud brick walls or placed between timber posts.

Generally, cob is partially or wholly stabilised by the aggregates and fibres that are used within it.

The use of cement and hydrated lime in cob forms in-situ adobe. The use of these materials is confined to SED. Section 7 gives information on this material.

Surface sealants or renders may be used to improve appearance, or to replace much of the cyclic maintenance that would traditionally have been needed.

6.2 Cob mixing

Earth for cob mix should be left for at least 12 hours after the initial mixing process and remixed before placing.

Some soils will make a serviceable mixture without soaking prior to placing and this can be established by trial.

Straw or other fibre is to be cut into lengths not exceeding half the finished wall thickness and added to the mix evenly.

C6.2

Cob can be mixed manually or by the use of a machine, such as a rotary hoe.

Generally, the earth is mixed with the aggregates, soaked, and remixed with the fibres. It is then allowed to soak overnight before remixing and placing directly onto the wall.

Straw or other fibres are added to a cob mix to help control cracking and help the uniformity with which cob dries.

6.3 Cob placing and bonding

Cob is placed in an overlapping pattern within continuous horizontal courses. Cob work is generally sloped at the ends and keyed to present a long sloping face to be worked in with subsequent work as work progresses.

Once placed on the wall, the material is firmly tamped down by hand or foot with each cob well keyed and worked into any adjacent cob and lower layers. Each section of cob must be deeply and well keyed to take every subsequent layer.

New work can be added on to a wall as soon as the wall below has dried enough to enable it to take the weight of the new work without distortion.

C6.3

Cob is placed on the wall until the wet cob will not stand further work being placed upon it without the faces bulging outwards. This can be as soon as overnight.

An overlapping pattern is necessary to ensure there are no vertical discontinuities where shrinkage could accumulate, resulting in a wide vertical crack.

The height of each layer of cob varies depending on wall thickness and mix stiffness but is generally between 200 mm and 300 mm per day.

It is important to ensure good bonding around corners and at intersections, where longer cobs can be moulded at once to help maintain good bonding.

A recommended method for keying is to form holes 40 mm to 50 mm deep and 30 mm to 40 mm diameter in the top surface at 100 mm centres.

The cob can be moulded true to finished line as work progresses or alternatively, once firmed up, the face of the cob wall can be trued up by cutting back.

Depending on the thickness of the wall and the weather, curing takes from one week to several months, usually at least four weeks.

Excessive exposure to wind or sun can accelerate surface drying and cause cracking.

6.4 Construction joints and cold joints

Before new work is added, the previous cob is to be wetted down.

If the previous layer has dried, then a layer of clay slip shall be worked into the wetted surface of the old work before adding the new.

6.5 Services and reinforcing

Cob is placed around vertical reinforcement and electrical conduits as the wall is built up.

Horizontal reinforcement is to be placed on cob that is soft enough to embed the reinforcing as the layers continue upwards, and is laid by pressing the reinforcing into a cob layer at least 50 mm thick with more cob laid above it and worked in that same day.

C6.5

Tests have shown that it is important for good bonding to embed reinforcing within the body of new work and not be placed directly between old and new work in a cold joint.

6.6 Shrinkage

Vertical settlement due to cob shrinkage shall be provided for when laying up the wall against fixed items such as posts. When fixing ties between cob work and items such as posts or joinery frames, all cob work below the level shall first be allowed to harden.

Fittings, frames, and vertical reinforcement embedded in the wall shall be detailed to allow for shrinkage to ensure that the shrinkage can occur unrestrained.

C6.6

If vertical shrinkage is restrained by other parts of the structure, then cracking due to 'hanging up' is likely to result.

6.7 Control joints

Control joints are not required (see 2.14.1).

C6.7

Horizontal shrinkage is controlled by the aggregates. Micro-cracking is controlled by the fibres in the mix and these prevent the aggregation of shrinkage into vertical cracks. Shrinkage can occur at posts and other fixed items, especially at the end of a section of wall. This shrinkage needs to be allowed for in the design.

6.8 Finishing

Low-density cob, with a density from 800 to 1400 kg/m^3 shall be coated with hydrated lime plaster externally and earth plaster internally in accordance with section 8. Heavy cob walls may be finished with either an earth or lime surface coating in accordance with section 8.

C6.8

Cob can be shuttered to shape vertical faces, but if end stops are used the material at the vertical joints needs to be well worked and keyed to endure horizontal continuity.

6.9 Repair of cob walls

6.9.1 *Repair of holes in cob walls*

For small areas of damage in cob walls that are not stabilised with cement, a patching mix of a similar composition to the original cob mix shall be used. This typically is a mix of one part clay soil and two parts coarse sand, with optional addition of finely chopped straw fibre.

The hole shall be brushed out to remove any lose material, and then thoroughly wetted with water to activate the stickiness of the original material. Clay slip shall be rubbed into the activated surface immediately before adding new material. The hole then shall be filled by hand-rubbing in some patching mix with enough pressure to get the aggregate to key into the damp surface, and then filling the rest of the hole to the shape of the original wall, either by hand or with a small trowel.

The repair shall be left to dry thoroughly before it can be finished off with the original wall finish to be concealed and blended in.

6.9.2 *Repair of cracks in cob walls*

Small cracks in cob walls that are not stabilised with cement shall be repaired with a patching mix of a similar composition to the original cob mix used. This typically is a mix of one part clay soil and two parts coarse sand, with optional addition of finely chopped straw fibre.

The crack shall be scraped out a bit deeper in a V shape using a steel blade, brushed out to remove any lose material, and then thoroughly wetted with water to activate the stickiness of the original material. Clay slip shall be rubbed into the activated surface immediately before adding new material. The hole shall then be filled by hand-rubbing in some patching mix with enough pressure to get the aggregate to key into the damp surface, and then filling the rest of the crack to the shape of the original wall, either by hand or with a small trowel.

The crack repair shall be left to dry thoroughly before it can be finished off with the original wall finish to be concealed and blended in.

7 REQUIREMENTS ADDITIONAL TO SECTION 2 FOR POURED EARTH AND IN-SITU ADOBE

C7 General

These methods include 5% to 15% Portland cement in the mixes to reduce shrinkage and to enhance the strength and durability of the walls.

If Portland cement is not used in the mix, then these methods should be regarded as a form of boxed cob, and the cob section used.

Hydrated lime or quicklime may sometimes be used also to help with stabilisation with some soils, or to limit shrinkage. Its use is subject to SED.

Poured earth

Formwork is set up to mould panels of such a size as to not be adversely affected by shrinkage. In some cases, large panels are made, while in other cases smaller blocks are cast upon which subsequent courses are moulded. Walls have been poured either in one unit or in a series of formwork lifts. Current practice usually involves setting up of a number of moulds in a castellated pattern and the casting of a series of single bricks with gaps between them. The sections are then allowed to set and shrink. Material is then cast to fill the gaps, or subsequent courses are made in such a way so that the vertical gaps between sections in the preceding lower course are filled. A number of proprietary moulding systems are available.

In-situ adobe

In-situ adobe is a technique closely allied to poured earth, except in-situ adobe uses a stiff cement-stabilised material placed into an adobe-brick-sized temporary mould smaller than the boxing units often used for poured earth panels, to contain the material as it is first placed upon the wall. The mould is removed immediately leaving the brick surface to be worked up into a monolithic wall with the desired surface finish as it stiffens and hardens. Some mixtures are stiff enough to be placed by hand in a manner similar to cob without a mould.

With in-situ earth building all the shrinkage takes place in the wall. Each course is required to bond to previous layers, and severe shrinkage will act against this, as well as causing destructive or disfiguring cracks.

The success of these methods of construction relies heavily upon selecting a soil mix that virtually eliminates the shrinkage that is inherent with these methods.

These techniques rely on there being just enough clay in the mix to provide initial moulding of the material before cement hydration occurs, while containing high volumes of aggregates to limit shrinkage. The use of cement with limited moisture in a stiff mix also helps reduce shrinkage. The effects of shrinkage are also overcome by limiting the size of cast units.

Minor shrinkage cracks, if they should occur, can be packed, or sealed with more mix or surface coatings if there is no risk of loss of structural or weathering integrity.

7.1 Material and mixes

7.1.1 *Soil*

Soils for poured earth should be soaked for at least 12 hours before moulding and the cement added just before final mixing and placement.

C7.1.1

With some soils the mix can be worked up from dry to give acceptable results.

7.1.2

Clay lumps larger than 12 mm shall be excluded from the mix. The maximum particle size for aggregates shall be 25 mm diameter.

C7.1.2

Test panels or previous experience with the proposed soil mix which demonstrates the suitability of particles larger than 25 mm can be satisfactory but are outside the scope of this standard.

Exclusion of larger particles is usually done by sieving but can also be done by pulverising. The presence of large lumps of unmixed clay on the surface of a wall can make the maintenance of a consistent surface finish or the application of renders particularly difficult.

While no specific range of particle sizes are proscribed, materials with a well-graded range of particle sizes will generally be found to be stronger and less porous.

Some successful in-situ adobe mixes have used two-thirds sand.

7.1.3 *Moisture content*

The moisture content of an earth mix for poured earth and in-situ adobe is critical to help control for shrinkage, and should therefore be limited to the minimum amount necessary for workability.

C7.1.3

Typically, with these types of cement stabilised mixes, around 50% of the shrinkage takes place within the first 48 hours and 90% within two weeks.

7.1.4 *Fresh mix containing cement*

All of a mix shall be placed and moulded within 45 minutes of the cement first coming in contact with water or damp earth except as provided for in 7.1.5.

7.1.5 *Stale mix containing cement*

Stale mix, being that which is older than 45 minutes from initial wetting, may not be used neat in a wall but may be used as up to 30% of the proportion of material in a new fresh mix. A fresh mix may comprise up to 30% stale mix and 70% fresh provided that fresh cement is added to this new mix as if there was no cement in the stale mix. All properties of the wall made with this mix containing part stale and part fresh shall fully conform in all regards to this standard as if there were no stale mix present.

C7.1.5

The use of mixes comprising part stale mix can be of different colour and if the wall is not to be coated, the use of stale mixes may not be suitable for aesthetic reasons.

There is no upper limit on the age of stale mixes that may be used, as long as conformance with this standard is not compromised.

7.2 Method of construction

7.2.1 *Moulds*

Earth mixes shall be placed into the moulds. While being placed, it shall be vibrated, rodded, tamped, or worked to create a homogenous wall free of voids, and to ensure that all reinforcing is well encapsulated and with the earth material. Vibrators must be used with extreme care to ensure that there is no segregation of particles within the mix.

The top surface shall be screed flat while the mould is still in place and then roughened to a minimum 5 mm amplitude, or otherwise left very well keyed before the material is fully hardened to enhance the bond with subsequent courses.

C7.2.1

The earth material is likely to be too stiff for vibrators to be effective but, if used, extreme care needs to be taken to ensure that there is no segregation of particles within the mix.

7.2.2 *Previous work*

The surface of previous work shall be thoroughly wetted immediately prior to placing of subsequent work.

7.2.3 *Height in a day*

The maximum height of wall that shall be added in a day is 450 mm.

> ***C7.2.3***
>
> *Wetting prevents premature drying at the joint and improves bond strength.*

7.3 Curing and drying

7.3.1 *Drying*

All work shall be moist-cured by spraying with either a concrete curing agent, by being covered with plastic film, or by covering with fabric kept damp for a minimum of seven days before being allowed to dry.

> ***C7.3.1***
>
> *Shelter the wall to limit excessive exposure to direct sun or strong wind that can cause uneven drying and consequential cracking.*

7.3.2 *Work containing cement*

All work containing Portland cement shall be moist-cured by being covered with fabric, which shall be kept damp for a minimum of seven days before being allowed to dry.

7.3.3 *Work containing lime*

All work containing hydrated lime shall be moist-cured by being covered with fabric, which shall be kept damp for a minimum of three weeks before being allowed to dry.

7.4 Surface coatings

Surface coatings may be used to improve appearance or enhance durability, as allowed for in section 8.

7.5 Formwork

Wall formwork may be manufactured in a wide range of sizes and dimensional proportions, with moulds or formwork shaped to allow for the units to be cast and the moulds removed without damage to the cast unit or adjacent work.

Limiting factors include:

(a) The height and thickness of the walls to be built;
(b) Structural integrity;
(c) The need to maintain bonding at corners;
(d) Excessive horizontal shrinkage with consequent cracking can occur with some soils, and this will be more pronounced the larger the placed or cast unit;
(e) The size and shape of the moulds (if any) to be used. Walls can consist of more than one brick to make up the specified thickness, but it is more common to use single-skin construction;
(f) The wall material can be moulded with holes to provide passage for services. These should generally be of small diameter (less than one-third of the wall thickness). Consideration can be given to drilling cores after initial drying.

7.6 Panel sizes

7.6.1

The maximum height of poured earth or in-situ adobe walls placed in one day shall be 450 mm.

Leave new work at least overnight before placing new work on top of old, once the maximum daily height limit has been reached.

Panel sizes over 450 mm high or more than 900 mm long cast in one piece shall be subject to SED.

C7.6.1

Some commercially available poured-earth boxing systems have a course height of around 300 mm.

Boxing for larger wall panels needs to be left until the wall can support its own weight without slumping or deformation.

The moulds have no top or bottom. In-situ adobe moulds are typically made from sheet metal or thin steel, poured earth moulds are usually stronger boxing. Moulds may have slightly tapering sides to ease the removal of the mould from the contained material.

There are no preferred sizes, although cast units especially in in-situ adobe, if longer than around 450 mm are often found to have excessive shrinkage. Consistency in cast unit thickness has an influence on the level of successive courses. In a commercial environment the amount of dimensional variation allowed may be nominated.

Unless shrinkage is very tightly controlled, pouring a wall with large panel sizes has generally not been found to be practical.

In practice it has been found that limiting the amount poured in one panel of block to less than 0.2 m^3 is a sensible limit for good performance.

7.6.2 *For poured earth*

Boxing shall not be removed, or the next lift shall not be poured until the fresh wall material, and the wall beneath it, are stiff enough to take the weight of the new work without deformation or damage.

7.6.3 *For in-situ adobe*

Forms are used to help shape the work and may be removed as soon as the material is placed.

The next lift shall not be placed until the layer beneath it is stiff enough to take the weight of the new work without deformation or damage to the older material.

C7.6.3

There are no preferred sizes for cast units of in-situ adobe, although units are usually about the same size as common mud bricks, often around 150 mm high with up to 450 mm long cast at one time before the next unit is cast. Maximum height is dictated by the amount of slumping that can be controlled by the stiffness of the mix.

Consistency in cast unit wall dimensions has an influence on the level of successive courses.

In a commercial environment the amount of dimensional variation allowed may be nominated.

7.7 Bonding

The earth mix is required to bond to previous layers and adjoining surfaces shall be well roughened and keyed to improve bond.

Poured earth or in-situ adobe blocks shall be cast in an overlapping bond pattern generally using a half bond where possible, and 100 mm minimum bond otherwise.

Wall sections shall be built up so as to maintain continuity of structure around corners.

Where a wall meets another, every course shall be bonded into the abutting wall.

7.8 Reinforcing for all poured earth or in-situ adobe

7.8.1 *Horizontal reinforcing.*

See either NZS 4299 section 6 or design details in accordance with NZS 4297 for reinforcing details. Install at a maximum of 450 mm centres vertically for mesh reinforcing in accordance with NZS 4299 clause 6.5 and at maximum 900 mm centres for steel bar reinforcing.

C7.8.1

Install the horizontal reinforcing at 300 mm centres vertically if the construction method allows it.

7.8.2 *Steel bar horizontal reinforcing*

Cut either a V or U-shaped groove approximately 50 mm wide and 50 mm deep to take a horizontal reinforcing bar into the top of the previous work once it is stiff enough to be worked without damage to the remaining wall materials. Ensure the rod is fully embedded in the freshly placed material.

7.8.3 *Geogrid reinforcing*

Place geogrid in a thin course of poured earth or in-situ adobe mix placed on previous work, with the geogrid embedded well into it before the next course of earth mix is placed on top of it while still wet.

C7.8.3

If full height wall panels are boxed and poured in one operation, then vertical and horizontal reinforcing bars may be placed inside the wall and tied together before the earth is poured subject to SED.

7.9 Shrinkage

Vertical settlement of poured earth caused by shrinkage shall be considered when detailing around services, or adjoining structure, or reinforcing steel (see 2.3.9).

C7.9

Walls made by this method can shrink vertically as well as horizontally, and allowance should be made when detailing against other materials or structure to ensure that the walls do not 'hang-up' on adjacent walls, joinery elements, or embedded reinforcing.

7.10 Control joints

7.10.1

Vertical control joints to control horizontal shrinkage shall be provided as required by 2.14.

7.10.2

All control joints shall be detailed to resist weather ingress.

7.11 Testing

7.11.1 *Samples*

Samples for compression testing or flexural tensile strength testing shall be cast into moulds as for adobe.

7.11.2 *Frequency and requirements*

These shall be tested as required by 2.5 and Table 2.1.

7.12 Repair of poured earth or in-situ adobe walls

Repairs of these materials shall be done in the same manner as repairs to pressed earth bricks.

8 SURFACE COATINGS

8.1 General

8.1.1

Surface coatings are not required on many earth wall surfaces, but may be applied to earth walls for a range of aesthetic, amenity, or serviceability reasons.

Although the application of surface coatings may be used to enhance the durability of earth building wall materials, except as provided by 8.2.2, such enhancement is outside the scope of this standard as a means of compliance with the materials and construction requirements of structures designed in accordance with either or both of NZS 4297 and NZS 4299 apart from that allowed by 8.5.2 and 8.5.3.

All surface coating work shall be performed by or under the supervision of people with the requisite skills and experience to ensure durability and appearance are of a high quality.

C8.1.1

The surface treatment of earth walls and their surface coatings or plaster layers can vary considerably from smooth and burnished to quite rough and uneven. For this reason, it is good practice to have a representative sample finish prepared and approved before final finishing or plastering takes place

8.1.2

Surface coatings may be used to enhance the durability of materials that are not excluded by 2.2.2 and 8.2.2 but shall not be used to make unacceptable materials able to be used.

8.1.3

Exterior plaster substrates and plaster systems that lack the minimum weather protection required by NZS 4299 clause 2.7 are outside the scope of this standard.

C8.1.3

Some relatively porous wall materials, such as low-density adobe or cob, are generally plastered for decorative reasons but also to generally improve and maintain serviceability.

Walls with even lower density and more open texture, such as light earth method (LEM) and straw bale, require surface coatings to give adequate serviceability.

Performance of various coating types

Traditional earth and lime coatings are vapour permeable and generally very compatible with earth surfaces.

Vapour permeable chemical treatments based on silicones, silicates, water and oil-based sealers, water resisting agents or paints, or lime-cement based renders can vary widely in their performance on different earths or different earth mixtures and their performance can be unpredictable.

Cement stucco generally has poor vapour permeability and can create moisture problems in an earth wall.

Some chemical or paint treatments that bond well with the surface layers or penetrate beyond the surface can work very well, while others can fail when moisture gets behind them and be sloughed off carrying the whole surface with them. They may vary widely in their performance on different earths or different earth mixtures and their performance can be unpredictable.

Sometimes a coating that performs well on one earthen substrate cannot do so on another.

Some commercially available earth and lime plasters, lime-based paints, or other coatings may carry manufacturers' warranties.

8.1.4

Although plaster coats in practice can contribute to the strength of the walls to which they are applied, no structural properties have been attributed to the plasters described in this section.

8.2 Purposes of surface coatings

8.2.1 *Uses*

Surface coatings may be used:

(a) To help limit moisture penetration;
(b) To help prevent erosion;
(c) To bind the surface and reduce surface dusting;
(d) For aesthetic or decorative reasons for colouring and for modifying wall surface texture;
(e) To improve general serviceability.

8.2.2 *Durability improvement*

Improved durability of a particular earth building material may be achieved by either:

(a) Improved weather protection or the erodibility index beyond the minimums provided for in NZS 4299 clause 2.7; or
(b) Improving the erodibility index of the material as per 8.2.3; and/or
(c) The use of appropriate surface coatings.

8.2.3 *Improvement of erodibility index of an earthen substrate by surface coatings*

The erodibility index of a material as measured by Appendix K or Appendix L may be improved by a maximum of one unit by the application of a surface coating subject to a suitable retesting result.

Any other improvement of the erodibility index or durability of an earth wall by the use of a surface coating is outside the scope of this standard.

Use of any earth wall material as a substrate that fails the wet/dry appraisal test as set out in Appendix J of this standard or fails the erosion tests of Appendix K or Appendix L is outside the scope of this standard whether a surface coating is applied or not.

C8.2.3

The use of surface coatings to improve otherwise unsuitable earthen materials, as can sometimes be required over historical or other surfaces that are at risk of failure in service, is outside the scope of this standard.

8.2.4 *Limits on erodibility index improvement*

A sample with an erodibility index of 2 after testing with either the spray test of Appendix K or the drip test of Appendix L may only be given an erodibility rating of 1 after the application of a surface coating and subject to a suitable spray test result after retesting.

A sample of material that gives an erodibility index test result of 3 or 4, for example, may have its erodibility index rating upgraded to 2 or 3 respectively subject to a suitable test result after the application of a surface coating.

C8.2.4

Although this provision may be regarded as conservative, the results of failure of a surface coating can be serious if the durability of the building is relying solely on the integrity of that surface coating.

8.3 Surface preparation

A wall surface that is to have a coating applied shall be dry, stable, and dust free and be prepared in a manner appropriate to the coating being used.

Surfaces are generally dampened with water, hydrated lime water, or very thin whitewash prior to the application of lime plasters and renders.

8.4 Coating materials

8.4.1 *Properties required of a coating*

Coating material shall exhibit the following properties:

(a) The surface coating shall bond to the substrate well;
(b) External surface coatings on earth walls (plasters, coatings, or paint) shall simultaneously limit the entry of water, yet have a high-water vapour permeability that is greater than 290 SI units;
(c) Surface coatings shall bind and stabilise the exterior surface of the wall;

(d) Any surface coating shall have durability to a level appropriate to the intended exposure of the wall being constructed;
(e) For plasters, an adequate key shall be provided by the surface texture of the substrate to ensure a good mechanical bond; and
(f) Any surface coating shall be resistant to degradation by ultraviolet light.

C8.4.1

Some exterior chemical treatments or paints can break down over time with UV exposure.

If the main concern with UV is the colour stability, then light-fast pigments should be used. If UV affects the colour, as it can with cow manure-lime finishes, this should be factored in but it is not an issue for durability.

8.4.2 *Unsuitable materials*

It is important for the good performance of earthen walled buildings that they are not coated with any impervious or semi-impervious surface coatings that can trap moisture within the wall. See 8.5.4.

The use of such material is outside the scope of this standard.

C8.4.2

This excludes the use of mineral oil, latex, or most acrylic-based paints, cement-based plasters, or lime cement plasters without a minimum lime content of 1:5 lime/cement ratio (see C8.5.3 and 8.11).

8.4.3 *Curing and drying of surface coatings*

All surface coatings shall be properly applied, dried, and cured.

C8.4.3

Limed-based plasters, renders or coatings require slow, controlled moisture curing and drying to ensure maximum adhesion and minimal cracking. Depending on the thickness of the coating, this may take up to seven days.

Good practice dictates that work shall be carried out in appropriate conditions for the specific plaster, render, or coating or per the manufacturers' specification. These are dependent on the type of plaster system or coating being applied.

When any colour changes caused by moisture in the material have completely gone then the material may be considered to be dry enough for any subsequent steps that require the substrate to be dry.

Full curing of cementitious or lime-based coatings may take up to two months.

Commercially available water vapour permeable paints or coatings applied over earthen walls or lime plasters should be applied in accordance with the manufacturer's instructions.

8.5 Coating types

8.5.1 *Coating requirements and overlays for inferior surfaces*

Minimum permeability levels of earth walls shall be maintained except where surfaces are adjacent to sanitary fixtures and sanitary appliances or are otherwise likely to be splashed or become contaminated in the course of the intended use of the building (splash zones).

To prevent the accumulation of moisture to levels which could form condensation on earth walls, buildings shall be adequately ventilated, particularly in spaces where moisture is generated.

Outside of splash zones, earthen interior walls surfaces may be left uncoated, and any surface coatings shall meet the minimum permeability requirements of 8.5.4. Within splash zones, earthen wall and floor surfaces shall be impervious and easy to clean. See 8.12.

C8.5.1

Many earth walls may be left uncoated on both internal and external surfaces and give satisfactory performance.

Earth walls are hygroscopic, that is, they absorb excess airborne humidity harmlessly, and then release this humidity when conditions reverse, thereby moderating humidity. The result is that earth walls in service rooms with adequate ventilation (for example, to NZBC Acceptable Solution G4/AS1) are unlikely to get condensation *forming on them. Sealing the walls with impervious coatings will prevent the hygroscopic earth from being able to cope so well with excess humidity if this should arise in these areas, leading to the possibility of moisture condensation on the walls and subsequent promotion of the growth of mould, and is therefore detrimental. It is not good practice to seal earth walls in bathrooms, kitchens and laundries with impervious coatings outside of splash zones, as these walls, because of their hygroscopic nature, help regulate humidity.*

Some earth walls can be dusty and could benefit from a surface coating. If wall surfaces are of softer earthen material, a suitable water vapour permeable surface coating, such as potassium silicate or a more durable plaster, such as lime plaster with a silicate mineral paint, can help make the surface harder wearing.

Clause 2.9 of NZS 4299 provides further information on measures for managing internal moisture in earth buildings, including for surfaces within splash zones.

Tadelakt is a lime-based waterproof plaster that is outside the scope of this standard.

8.5.2 *Lower-density materials*

Lower-density materials, such as low-density adobe, low-density cob, straw bale, and LEM, are more serviceable with a more dense and harder-wearing surface and shall have a lime plaster on the exterior and either a lime or earth plaster, on interior surfaces.

C8.5.2

See also NZS 4299 Appendix D and Appendix E. Some earth plasters may be suitable for exterior walls of straw bale or LEM but are outside the scope of this standard.

8.5.3 *Exterior coatings*

Water resistant but water vapour permeable coatings may be used to improve the serviceability, performance, and resistance to moisture penetration of external walls.

8.5.4 *Permeability and permeance*

No coating should be applied to an earth, LEM, or straw bale wall that has a vapour permeance of less than 290 ng/Pa.s.m^2 (SI unit).

The coatings in C8.5.4 (f) to (m) and in C8.5.5 (a) to (g) are deemed to have adequate permeance for application to earth, LEM, or straw bale walls.

C8.5.4

Some relatively porous wall materials, such as low-density adobe or cob, are generally plastered for decorative reasons but also to generally improve and maintain serviceability.

Walls with even lower density and more open texture, such as LEM and straw bale, require surface coatings to give adequate serviceability.

Performance of various coating types

Moisture will inevitably migrate into the wall from the interior and/or exterior behind the coatings. The degree of permeability, sometimes referred to as breathability, is an important factor when choosing surface coatings.

The following factors have been taken into consideration in this standard when considering surface coatings.

Finding reliable or agreed absolute figures for permeance or permeability or setting limits on them is not straightforward and materials can be measured in different ways, using different units.

There is wider agreement about the relative permeability or permeance of different plaster and coatings systems. Traditional earth and lime coatings are vapour permeable and generally very compatible with earth surfaces.

Vapour permeable chemical treatments based on silicones or silicates, water and oil-based coatings or paints, or lime-cement-based renders can vary widely in their performance on different earths or different earth mixtures and their performance can be unpredictable.

Cement stucco without lime is effectively a vapour barrier and can create moisture problems in an earth wall.

Some chemical or paint treatments that bond well with the surface layers or penetrate beyond the surface work very well, while others fail when moisture gets behind them and can be sloughed off carrying the whole surface with them. These treatments vary widely in their performance on different earths or different earth mixtures and their performance can be unpredictable.

Sometimes a coating that performs well on one earthen substrate will not do so on another.

LEM and straw bale walls are more moisture sensitive than denser earth walls, and the drying ability of a water vapour permeable coating becomes an essential part of the mechanism for keeping walls dry.

As a guideline, no surface coating (that is paint, sealer, or plaster) with a permeance less than 290 ng/Pa.s.m² (SI unit) should be applied to the surface of an earth, LEM, or straw bale wall. This minimum also applies to the permeability of any abutting sheet materials plus finish that may form or act as a surface coating.

This minimum is readily reached by earth and lime plasters, which have permeance figures typically starting at around 500 ng/Pa.s.m² for lime plasters and ranging up into the thousands for lime washes.

Permeability figures are very hard to be sure of, as different authorities give widely different figures, but some indicative and approximate permeance figures are given here for guidance purposes only.

The more water-vapour permeable the layer, the higher the permeability figure. The thicker the layer, the more it resists the water vapour and the lower the permeance becomes.

Surface layer	***Layer thickness***	***Permeance (ng/Pa.s.m²)***	***Acceptable permeance?***
1:3 cement/sand plaster (Note 1)	*25 mm*	*70*	*No*
1:5:15 lime/cement-sand plaster (Notes 1 and 2)	*38 mm*	*230*	*No*
1:5:15 lime/cement-sand plaster (Note 2)	*25 mm*	*345*	*Yes*
1:1:6 lime/cement-sand plaster	*25 mm*	*415*	*Yes*
2:1:9 lime/cement-sand plaster	*25 mm*	*600*	*Yes*
1:3 lime/sand plaster	*25 mm*	*670–750*	*Yes*
Earthen (clay) plaster	*25 mm*	*670–1200*	*Yes*
Straw clay (1250 kg/m³)	*38 mm*	*1080*	*Yes*

NOTE –

(1) Not permitted – included for interest only.

(2) Minimum lime content allowed – note the effect of increased thickness on permeance.

(3) The permanence figures used here are SI units and are in nanograms per second per square metre per pascal of water vapour pressure or (ng/Pa.s.m²)

The metric perm (not an SI unit) is defined as 1 gram of water vapour per day, per square meter, per millimetre of mercury water vapour pressure.

The US perm is defined as 1 grain of water vapour per hour, per square foot, per inch of mercury. The following conversion factors can be helpful:

(a) US perm × 0.66 to get metric perm;
(b) US perm × 57.2 to get ng/Pa.s.m² (SI unit);
(c) Metric perm × 86.8 to get ng/Pa.s.m² (SI unit); and
(d) SI perm × 10^{-9} to get ng/Pa.s.m² (SI unit);
(e) For water vapour permeability expressed in g/(MNs), divide by 0.001 to get the equivalent SI units in ng/Pa.s.m².

Suitable coatings in decreasing order of water vapour permeability include:
(f) Bagging with a clay-based slurry;
(g) Earth plasters with or without natural additives, for example cow dung, casein, wheat paste;
(h) Pure whitewash (limewash) or lime-based paint;
(i) Lime plasters;
(j) Lime-casein paints;
(k) Potassium silicate mineral paint;
(l) Water vapour permeable silane-siloxane sealants;
(m) Lime-based paint with the addition of fat or oil.

8.5.5 *Dust reducing coatings*

Internal dusting from some earthen surfaces may be reduced by using finishes with adequate vapour permeability.

C8.5.5

Suitable coatings in increasing order of serviceability include:

(a) Diluted casein-borax glue or cellulose glue (wallpaper size);
(b) Clay-based paints;
(c) Whitewash (limewash) or lime-based paint;
(d) Lime-casein paints;
(e) Potassium silicate mineral paint;
(f) Earth plasters with or without natural additives (for example, cow dung, casein); and
(g) Lime plasters.

8.6 Bagging

Bagging involves rubbing a thin layer of clay slurry, with or without natural additives, such as fine sand or cow manure, into and all over the surface.

C8.6

Bagging is particularly suitable for adobe and is thin enough to reveal the brickwork pattern underneath.

The walls should be gently wetted with water and bagging done while the wall is still damp.

Trial mixes need to be done to establish suitable mixes.

8.7 Earth plasters

Earth plaster is a traditional treatment for adobe and cob walls and is normally applied in two or three coats, in protected exterior areas, and on interior surfaces. All earth plastering work shall be performed by or under the supervision of people with the requisite skills and experience to ensure durability and appearance of a high quality.

C8.7

For earth plasters applied to exterior walls, assessment of suitability relies on experienced knowledge of the particular materials used and careful assessment of weather exposure of the wall. Their use as a protective coating is outside the scope of this standard.

The first coat of earth plaster, made of screened fine clay and well graded sharp 0 to 3 mm sand, is usually reinforced with finely chopped straw or other fibrous material and applied approximately 10 to 20 mm thick. Clay and sand ratios will depend on the earthen material used. Test patches should be carried out to find a suitable mixture.

The finish coat is made of fine screened clay and up to 2 mm sand but usually without the addition of fibres and is applied as thinly as possible.

Natural additives including cow manure, cellulose (paper pulp), casein-borax glue, or cooked flour paste, which all increase surface hardness, may also be added to the earth plaster.

A way of hardening the surface is to consolidate it by rubbing with a damp sponge or polishing it with a flexible steel or plastic trowel.

Earth plasters have also been successfully applied to other substrates such as straw bale, LEM, concrete block, plywood, carpet, or interior plasterboard.

8.8 Whitewash or limewash

Limewash should be applied very thinly to clean dust-free surfaces in at least three or four coats. It is important to not work in conditions that are too hot and dry. Surfaces should be misted with water before and after limewashing to slow down drying to allow time for the whitewash to cure. One day of curing between coats is recommended.

C8.8

There are many well-tried recipes for limewash, which can be improved to last longer with additives including skimmed milk, casein, and cow dung.

Old lime and new limewashes are very compatible.

8.9 Gypsum plasters

Gypsum plaster may be used on interior surfaces only or as a finishing coat over other internal plaster that complies with this section if investigation shows that its permeance is less than 290 ng/Pa.s.m^2.

Gypsum plaster shall not be used on exterior surfaces.

C8.9

The vapour permeability of gypsum-based coatings can vary depending on the source of the gypsum, so gypsum plasters need to be used with care.

Gypsum plaster is suitable for interior earth walls only and usually is applied in two coats although it can also be used for bagging. Mixing one part gypsum with two to three parts of sand will increase the bulk of the plaster but will also make it set more quickly. Waterborne pigments may be added.

8.10 Lime plasters

8.10.1 *General*

Lime-based plasters are suitable for exterior walls with minimum weather protection complying with NZS 4299 clause 2.7, where an exterior coating is a mandatory requirement of the standard, including for low-density earth walls, or for interior applications.

Lime plasters are suitable over solid, porous surfaces, such as low-density adobe and cob, high-density adobe and cob, pressed brick, rammed earth, LEM and compressed strawbales.

Their application over earthen plaster base coats is outside the scope of this standard.

C8.10.1

Lime-based plasters provide a durable and vapour permeable protective finish.

Lime-based plasters are generally more weather resistant than earthen plasters.

They have similar thermal expansion properties to earth.

Good practice dictates that work should not be carried out in direct sun, when conditions are dry, windy, and hot, or if there is risk of freezing. It is good practice to provide shading and lightly mist the render with water during curing.

It is very important that the detailing around openings and lintels is done with care, as ingression of water in these points can lead to delamination of the lime plaster.

8.10.1.1 Work quality

All exterior lime plastering work shall be performed by or under the supervision of people with the requisite skills and experience to ensure durability and appearance of a high quality.

A high-quality surface finish can be achieved by sponge floating the surface in a circular motion when the lime plaster has hardened up sufficiently, and then hard trowelling with a stainless steel or plastic trowel with a flexible blade.

C8.10.1.1

Lime plastering of earth walls is skilled work and the practice is based on tradition and site experience. A skilled person can demonstrate previous experience of successful lime plaster work over solid earthen substrates.

8.10.2 *Lime plaster materials*

8.10.2.1 Composition

Lime plaster shall be made from lime putty and sand and may contain fibres such as chopped straw, fine animal hair, or fine polypropylene fibres.

Lime putty is obtained by either slaking quicklime or soaking fresh hydrated lime powder in water.

Slaking times can vary from a week for hydrated lime to several months for quicklime. The putty shall be well covered with water while it is stored to avoid it reacting with carbon dioxide in the atmosphere.

Longer periods of slaking make the putty stickier and better to work with and this storage time may extend to several years.

Lime plaster systems shall be made up of two or three coats.

The ratios given in 8.10.2.2 and 8.10.2.3 can be used as guidelines.

C8.10.2.1

The mixes here are based on widely used and time-tested recipes. There are many different possible plaster mixes, including those that use cow or other animal manure, pozzolanic sand, or other additives, but these are outside the scope of the standards.

Although it is not essential to use a fibrous mix, the inclusion of fibres reduces the risk of cracking and shrinkage.

Hair

Goat, cattle, and horsehair are all suitable. Hair should be added to the mix just before use. Do not add hair to a mix that is to be stored for more than about four weeks as the hair will rot if left in damp lime mortar. Human hair may also be used but the fibres should be chopped short, and 50 mm maximum lengths is suggested as a guideline.

The hair should be gradually added into the mix so that it is well distributed and does not form clumps. As a general rule, add 5 mg of hair per cubic metre of plaster for walls.

For the second coat use half the quantity of hair.

To check whether there is sufficient hair in the mix, scoop some mix into a gauging trowel, tap the underside of the trowel vigorously against the top edge of a bucket so that the blob flattens, and the surplus mortar falls off the edge of the trowel.

There should be a fringe of hair at roughly 1 mm intervals around the edge of the trowel.

8.10.2.2 Base coat(s)

The lime plaster base coat shall be 2.5 to three parts well-graded coarse sand with optional fibre to one part lime.

This may also be used as an exterior finishing coat or topcoats.

C8.10.2.2

Most well-graded plaster aggregates, regardless of the particle size, have a void ratio of around one-third, hence a 1:3 (lime/aggregate) mix is generally used.

8.10.2.3 Interior or exterior finishing coats or topcoats.

The lime plaster interior or exterior finishing coat or topcoat shall be:

(a) One part lime to one part well-graded fine sand and fibre (fine animal hair or polypropylene fibre); or
(b) One part lime to two parts well-graded fine sand without fibre.

C8.10.2.3

A higher amount of lime allows for a smoother finish, but lime-rich coats should be applied very thinly to minimise shrinkage cracking. A very fine finish can be obtained by using agricultural lime as a finishing aggregate instead of sand.

8.10.2.4 General guidelines for mixes

A general rule with plasters is that each coat should contain the same ratio, or be slightly richer in lime, than the preceding coat.

The aggregates should generally be coarser in base coats and external finishing coats, and finer for internal finishing coats. This varies slightly depending on the aggregate used.

The base coats typically consist of the optimal amount of lime to aggregate, where all aggregate voids are just filled.

The finish coat should be richer in lime, or of the same ratio as the base coats.

The ratio of lime may be decreased, and/or setting times decreased by the addition of some pozzolanic materials, but the use of such material is outside the scope of this standard.

8.10.2.5 Contact with timber

Untreated timber or timber treated to a standard below hazard class H3 shall be separated from lime plaster that also contains cement by a damp-proof course or bituminous or similar building underlay.

8.10.2.6 Curing lime plaster

The plastered wall shall be protected from full sun, and the wall shall be misted with water for at least 7 days after completion to support the curing process.

C8.10.2.6

Adequate care of freshly plastered walls is important and will influence the quality of the plaster job. The lime plaster will undergo a carbonation process for many months.

It is recommended that exterior finish coats are protected by additional coatings such as:

(a) Several coats of lime wash which get regularly reapplied; or
(b) Two coats of silicate mineral paint.

Lime work is best carried out in ideal weather conditions, at temperatures no warmer than 25°C, no cooler than 5°C and not in windy conditions. This restricts it to late spring and early summer or early autumn in many areas as this is dependent on the local environmental conditions. It is crucial that fresh lime plaster is not exposed to freezing for several weeks after completion.

Lime plastering should be carried out by someone experienced in this kind of work, or under the supervision of someone experienced in the use of this material.

Lime is very caustic and adequate protective measures should be taken to be safe.

Lime plaster placed over earth plaster skins is particularly dependent on a good mechanical key between the two materials and experienced knowledge of local materials. Although there are examples where this has been successfully done, and historical precedence can be used to demonstrate that some particular materials do behave effectively, there are also instances where lime plasters over earth plasters have failed. A plaster skin is unable to absorb as much moisture as thicker solid earth walls. This increases the risk of failure if the interface between these materials becomes moist. Its use is outside the scope of this standard.

Do not use chicken wire or metal lath to reinforce or attach lime plasters as it can cause stress in the render due to differential thermal movements and may lead to large-scale failure if it corrodes. See 8.10.8 and C8.10.8.

8.10.3 Lime-cement plaster

Lime-cement plaster should contain minimum lime content of at least one part hydrated lime to five parts of cement or 15% hydrated lime/cement ratio to give a minimum acceptable vapour permeability, and should contain reinforcing mesh.

Cement plaster with less than a minimum lime content of 1:5 lime/cement ratio shall not be applied directly to any earth, straw bale, or LEM walls.

C8.10.3

Cement plasters with minimum lime content of 1:5 lime/cement ratio may be applied to cement stabilised earthen substrates as a slurry wash or plaster. They are generally not used apart from over cement stabilised substrates. They tend to be brittle so require the addition of plasterer's mesh as the plaster is less likely to bond well to earthen substrates, especially softer ones, than pure lime plaster. Reinforcing mesh needs to be mechanically attached to the substrate and any boundary members.

Cement-based plaster with less than 1:5 lime/cement content effectively acts as a semi-permeable, or impermeable, coating that can attract and hold moisture against or inside an earth wall to the detriment of the wall.

Cement-based plasters may be used as a cladding over a ventilated drained cavity as per NZS 4251.1.

Untreated timber or timber treated to a standard hazard class H3 or below should be separated from plasters containing cement-lime by a damp-proof course or bituminous building underlay.

8.10.4 *Plaster reinforcement*

Well-keyed solid earth surfaces generally function very well as a substrate for plasters, and no other lath or mesh should be required except as required for in-plane or out-of-plane resistance as may be required by SED.

Plaster systems may include mesh or reinforcing fibres to control cracking and micro-cracking.

Mesh may include loose-weave hessian or jute, polypropylene mesh (see 8.10.6), fibreglass mesh (see 8.10.7), or other plasterers' mesh such as galvanised steel mesh in some limited circumstances (see 8.10.8).

C8.10.4

Reinforcing fibres may include chopped straw sisal, hemp, hessian or jute, animal hair, or polyester fibres.

Some practitioners recommend installing additional mesh in plasters at corners to walls and/or at corners of openings to improve their robustness.

8.10.5 *Mesh to joints between earth with other materials*

Where earth abuts other materials, mesh complying with this section shall be used to bridge the joints and to prevent cracking with all types of plaster. Any non-earth substrate shall be covered by a slip layer of building underlay before plaster is applied.

Mesh shall be embedded in the first coat of plaster during plaster application and shall extend a minimum of 200 mm onto the face of the earth.

C8.10.5

For example, when plaster is applied over the join between earth and timber, earth and metal, or earth and sheet material, the timber, metal, or sheet materials shall be first covered by a slip layer of building underlay. The slip layer prevents hang up of the plaster on the non-earth substrate and when combined with mesh prevents cracks forming at the joint.

Mesh may be attached to the face of earthen substrates with stainless steel wire U-pins or staples if necessary.

For edge fixings see 8.10.10.3.

8.10.6 *Polypropylene mesh*

Extruded polypropylene mesh shall have a minimum weight of 70 g/m^2 with a minimal tensile strength of 4.5 kN/m in both the longitudinal and transverse directions.

C8.10.6

One suitable manufactured extruded polypropylene mesh weighs 70 gm/m^2. Mesh size is 21 mm × 34 mm with tensile strength in the longitudinal direction of 4.5 kN/m and in the transversal direction of 6.5 kN/m.

8.10.7 *Fibreglass mesh*

Fibreglass mesh shall be alkaline resistant, with a minimum density of 60 g/m^2 for interior walls and 160 g/m^2 for exterior walls, and a minimum mesh size of 8 mm.

C8.10.7

Fibreglass mesh generally has small apertures so can be difficult to use with stiffer or coarser mixes.

8.10.8 ***Galvanised steel mesh***

Steel mesh shall be galvanised and shall only be used in a lime-cement plaster, and only where the lime/cement ratio is between 1:2 and 1:5.

C8.10.8

Chicken wire is commonly used as galvanised steel mesh reinforcing. It is made from flexible galvanised steel wire, between 0.7 mm and 1.0 mm diameter (19 to 22 gauge) with hexagonal gaps that are around 25 mm across.

Due to its flexibility, chicken wire can be used on curved and angled surfaces.

Steel mesh reinforcing has a different thermal expansion rate to clay and lime-rich plaster. It can be prone to corrosion even when galvanised in pure lime, lime-rich earth, or gypsum plasters. Its use should be confined only to a cement-based plaster with a low lime content or proprietary plaster mixes that may carry a warranty.

8.10.9 ***Mesh embedment in plaster***

Mesh shall be centrally embedded in the main coat of plaster except at the points where staples fasten the mesh to boundary elements. See 8.10.11.

If lime or earth plasters containing a high volume of chopped straw or other fibres are applied with a mesh, the body coat of plaster should be applied in two layers with mesh embedded between the layers while wet.

C8.10.9

Mesh embedment is a good technique for earth plasters, but embedding mesh into lime plaster can be dangerous when attaching the mesh to the structure over an initial fresh lime plaster layer because of the caustic nature of the lime and the high risk of burns from splashing.

If lime plaster has high volumes of straw the mesh should be attached at the top first, pulled out of the way while the plaster is keyed into the substrate, and then the mesh should be placed into the plaster.

8.10.10 ***Mesh covering entire walls***

8.10.10.1 Application

Mesh in plasters over whole earth walls should be installed in accordance with this clause.

C8.10.10.1

Mesh should only be required over whole earth walls in specific situations when there isn't adequate key or the plaster has to be thicker.

8.10.10.2 Mesh laps

Mesh, where required, should be installed with not less than 150 mm laps and laps securely joined together.

8.10.10.3 Mesh attachment

Mesh should be attached with staples to top plates or roof-bearing elements, to bottom plates and any vertical posts, poles, or framing at the edges of plastered areas in accordance with the following:

(a) Staples to the exterior wall faces should be pneumatically driven, stainless steel, 1.29 mm diameter (16 gauge) with 38 mm legs, and 11 mm crown. Galvanised steel staples may be used in cement or lime plasters only;
(b) Staples to interior wall faces may be as for exterior wall faces or manually driven, stainless steel,1.29 mm diameter with 25 mm legs. Galvanised steel staples may be used in cement or lime plasters only;
(c) Staples into CCA-treated or other treated timber should be stainless steel or in accordance with NZS 3604;
(d) Staples should be oriented diagonally across mesh intersections at the required spacing; and
(e) Staples should be spaced at not more than 150 mm centres.

8.10.11 *Spacers*

Spacers shall be placed between mesh and supporting timber or structure to ensure that mesh is well embedded within the first coat of plaster.

See Acceptable Solution E2/AS1, section 9.3.

Steel mesh shall be separated from preservative treated timber hazard class H3 or greater by bituminous building underlay or other damp-proof barriers.

8.10.12 *Control joints*

Control joints are not required in earth or lime plasters or renders unless plaster or render covers a control joint in the substrate when a control joint shall also be provided in the plaster.

C8.10.12

Control joints are generally not required in earth or lime plasters or renders. Earth and lime plasters are softer than cement stucco and less brittle, so tend only to evenly distribute micro-cracking, especially if they contain fibres Lime-cement plasters are more brittle, so some practitioners do put control joints in them in long walls (that is over 3.6 m long) or where the height of a wall changes, for example, at each side of a window opening.

8.10.13 *Openings and penetrations*

8.10.13.1

Openings and penetrations in areas to be plastered shall be formed prior to plastering. Weather penetration around door and window opening in exterior situations shall be prevented by the installation of head, sill and side flashing systems that are free draining to the exterior.

8.10.13.2

Flashing details for head, sill, and jambs for plastered exterior earth wall are shown in NZS 4299 section 10.

8.10.13.3

Service penetrations through the plaster larger than 150 mm in diameter (such as meter boxes) shall be fully flashed.

8.10.13.4

Small service penetrations (up to and including 150 mm diameter or equivalent area) such as waste pipes, shall be installed so that they are supported by the solid earth wall, slope downhill to the outside and are sealed against moisture penetration.

8.10.13.5

The hole for the penetration should be at least 15 mm greater in diameter than the pipe or conduit to allow sufficient sealant thickness to accommodate movement without failure. The sealant shall be forced against a backing rod and be protected from the weather on the outside by a close-fitting flange around the pipe.

8.10.14 *Application and curing of exterior lime-based plaster over earthen substrate*

8.10.14.1

Before the application of the base coat, the solid substrate shall have adequate roughness to ensure good mechanical key (good bond).

Before plastering, the surface should be roughly brushed to remove loose material and shall be dampened with water or lime water to promote good adhesion. There shall be no free water on the surface at the time of plaster application.

C8.10.14.1

On wall surfaces of low-density earthen materials that are to receive plaster, good mechanical key may be achieved by the texture of the raw wall alone. On wall surfaces of denser earthen materials, good mechanical key may be achieved by scratching up the surface or by lightly pointing the mortar joints of brick walls. On very smooth and hard earthen substrates, good mechanical bond may be achieved through a stipple coat flicked on or applied by Tyrolean machine or texture gun.

8.10.14.2

The basecoat shall be applied with sufficient pressure to ensure continuous contact with the solid earthen substrate.

Excessive steel floating should be avoided as this tends to bring the lime and fine sand to the surface.

The finished base coat surface shall be scratched with a suitable tool to leave grooves approximately 5 mm deep spaced at 15-20 mm intervals, to ensure good bond for the finish coat.

C8.10.14.2

A machine pump designed for the purpose of applying cement-based plaster may also be used for applying the lime-based basecoat and might provide a superior bond to the substrate due to the mix being thrown on.

8.10.14.3

The base coat should be left curing at least overnight and for up to three days, ensuring the surface gets misted with water at least once a day before applying the finish coats or topcoats.

8.10.14.4

Finish coats or top coats can be applied in one or two coats, depending on the desired finish. One coat is sufficient for a sponged finish. For smoother finishes a second finish coat may be applied. Plaster thicknesses are specified under 8.10.15.

8.10.14.5

The finish coat or topcoat should be cured by daily misting with water for five days.

Enough time should be allowed for carbonation of fresh lime plaster, before applying any further surface treatments. Lime wash can be applied within two weeks, mineral-silicate-based (waterglass) paint or other vapour permeable surface treatments after a carbonation period of two months.

Refer to section 8.5.4 Permeability and permeance.

8.10.15 *Plaster thickness*

The total plaster thickness shall be measured from the face of the solid earthen substrate and in exterior situations shall be no less than 20 mm. Plasters of a total thickness greater than 30 mm shall be supported by a mesh in accordance with 8.10.10.

Base coats typically range from 12 mm to15 mm in thickness.

Topcoats or finish coats typically range from 6 mm to15 mm thickness, depending on how textured they are (trowelled, sponged, or hand-thrown rough cast).

8.11 Impervious coatings for splashbacks or splash zones.

Impervious coatings shall be made by fastening a water-resistant fibre cement board as a substrate as per NZS 4299 2.9.3 and finishing this with a waterproofed and tiled surface.

The junction between an impervious surface and any sanitary fitting shall be sealed with a suitable silicone sealant.

Other junctions to adjacent earth wall surfaces shall be made as per NZS 4299 2.9.3.1 or as C8.10.5

8.12 Plaster finishes and maintenance

Suitable water vapour permeable finishes to surface coatings include earth plasters, clay-based paints and washes, mineral-silicate-based paints, lime-based paints, or whitewash. Finishes that are not vapour permeable, that is with a permeance less than 290 SI units, must not be used except where small interior areas of impervious splash backs are required as per 8.5.1 and 8.11.

Surface coatings need maintenance to maintain their necessary performance protection for the life of the building, to prevent them becoming damaged or degraded. Subsequently, surface repairs or maintenance shall not adversely affect the water vapour permeance of any surface coating.

C8.12

The permeability performance of a coating is easily overwhelmed by the movement of moist air in, out, or through the wall, so to achieve good coating performance it is most important that the coatings or plasters are well applied, well maintained to remain intact, and free of any cracks or gaps.

The permeance of a coating or finish will be adversely affected by the subsequent application of a different paint system with poor vapour permeability.

Worked example showing the effect of an unsuitable paint system

The addition of a coat of paint to a coating system with adequate permeance can lower the permeance of the whole cladding system, taking it well below an acceptable figure.

An example of a likely permeability calculation (using the symbol P for permeance) would be:

$1/P_{total} = 1/P_{plaster} + 1/P_{paint}$

If $P_{plaster} = 300$, *and* $P_{paint} = 300$, *then* $P_{total} = 150$ *ng/Pa.s.m*^{2}*, which brings it well below the guideline.*

The application of any further coating of such paint further significantly decreases the permeance of the cladding system, which significantly increases the risk of moisture retention in the walls.

Frequency and cost of maintenance choices

The wide range of different surface coatings have two distinctly different approaches. Natural earth and lime washed finishes can be achieved simply and at initial low cost. The lower initial cost can be offset by higher maintenance costs due to the need for more frequent surface treatment, but this is also relatively simple and inexpensive.

Directly applied waterproofing vapour permeable silicone, silicate, or siloxane treatments sometimes used on masonry or concrete have a history of failure over many earthen surfaces and are no substitute for good primary rain deflection being built into the design.

More permanent, water-repellent surfaces, such as lime plasters with mineral silicate-based paint or vapour permeable silicone or siloxane, are more expensive initially, but will require less frequent but more complex maintenance, which can create higher long-term maintenance costs.

Some commercially available earth and lime plasters, lime-based paints, or other coatings can carry manufactures' warranties.

Plaster coatings should be inspected annually, and also after any major earthquake or storm event, and if damaged, repaired as necessary.

For more information refer to 'Using Natural Finishes' by Adam Weisman and Katy Bryce, 'The Natural Plaster Book' by Cedar Rose Guelberth and Dan Chiras, or publications by the UK Lime Association.

8.13 Repair of lime plaster

8.13.1 *Repair of holes and chips in lime plaster*

For small areas of damage in lime plaster coatings, the surrounding plaster and exposed substrate shall be dusted off thoroughly and misted with water. The repair shall then be carried out using a lime plaster finish coat mix.

If the area of damage is deeper than 10 mm or all the way to the substrate, the repair shall be applied in two layers.

The first coat shall be thrown on to ensure good bond, and be either smoothened, or left rough if there is a second coat. The second coat shall be applied one day after the first coat, and the first coat should be misted with water before work continues. Once the hole is filled, the last layer shall be sponged to blend in the surface of the repair with the surrounding plaster.

The repair shall be left to cure for one week before it can be finished off with the original wall finish to be concealed and blended in.

8.13.2 *Repair of cracks in lime plaster*

Hairline cracks of up to 1 mm in lime plaster shall be filled with lime wash or other suitable paint, such as mineral-silicate-based paint with the addition of a small amount of very fine silica sand.

Small cracks up to 5 mm in lime plaster shall be repaired with lime plaster finish coat.

The crack shall be scraped out a bit deeper in a V shape using a steel blade, brushed out to remove any lose material, and then misted with water. It then shall be filled with lime plaster finish coat using a small trowel, and gently sponged to blend in the surface of the repair with the surrounding plaster.

The repair shall be left to cure thoroughly as per 18.13.1 before it can be finished off with the original wall finish to be concealed and blended in.

8.14 Coatings for earthen floors

8.14.1 Sealing of earthen floors

Earth floors shall be sealed after installation to prevent dusting, increase strength, and to provide resistance to penetration by water or other fluids. After the floor is cured and dried, a minimum of four coats (usually four to six coats) of thinned hardening oil shall be applied to the floor until the surface is fully saturated. The last coat of oil shall be applied unthinned. Suitable hardening oils are boiled linseed or tung oil or a mixture of both.

The coats shall be applied in succession over a 48-hour period, without more than a 12-hour lag between coats. Each coat of oil shall have completely penetrated before the next coat is applied. Initial coats can be applied almost immediately, later coats may take hours to penetrate fully. It is good practice to thin initial coats more, reducing the amount of thinner in subsequent coats, and applying the last coat unthinned.

Saturation is obtained when the surface can no longer absorb more oil, and oil starts to pool. Any excess oil pooling on the surface after six hours shall be wiped off to prevent it from polymerising and forming a skin, as it is very difficult to remove this.

C8.14

Tests for suitability of all surface coatings should be carried out before application. Note that some surface coatings can change the colour of a floor significantly.

An earth floor is cured and dry once it has become hard and any moisture-induced wet colouration has completely gone. To check for dryness, a sheet of impervious material such as a 1.0 m x 1.0 m square of polythene may be taped around its edges to the floor. It should not have moisture condensed beneath it when lifted after 24 hours.

Hardening and resistance to moisture in an earth floor is enhanced by the application of an appropriate thinned hardening oil, which deeply penetrates the dry surface. Hardening oils are also sometimes known as drying oils. During the drying process, these oils undergo polymerisation, resulting in the amalgamation of earth particles and the creation of a durable, water-resistant surface layer. Suitable oils are boiled linseed oil, tung oil, or a combination of the two.

For optimal absorption, it is recommended to combine the hardening oil with a thinner such as mineral turpentine, citrus oil, or gum/pine turpentine.

A commonly used ratio is three parts hardening oil to one part thinner.

Oil and thinner ratios

Tung oil has very high strength, but poor penetration. It should be cut with 30-50% thinner in order to improve penetration.

Boiled linseed oil has high strength and moderate penetration. It should be cut with 25% thinner to improve penetration.

Linseed oil does not perform as well as tung oil where it is likely to experience high humidity, or in moist conditions, as it does not polymerise as strongly as tung oil.

Blending oils can capture the benefits of each. A blend of one part tung oil and one part boiled linseed oil, cut with 25% thinner works well.

The amount of thinner can be reduced by 5% for every subsequent coat, with the last coat not being thinned at all.

Some commercially available floor oils based on hardening oils are also suitable for this purpose.

The oil may be applied with a brush or a paint roller.

The oil application process should be carried out in a well-ventilated environment while utilizing appropriate personal protective equipment (PPE). Adequate ventilation should also be maintained during the subsequent oil curing period, which may extend up to a week or more.

An optional measure for enhancing durability and sheen involves the application of an additional layer of floor wax, although this step is not obligatory. Alternatively, it is feasible to incorporate hardening waxes and resins (such as carnauba wax) into the final oil coat, or to employ a suitable commercial floor oil or wax product for the concluding coat.

***Caution**: All rags used with these oils must be carefully spread out to completely dry, or else disposed of in a fire, as they have been known to spontaneously combust under some conditions if left bunched up with oil on them.*

Sealed earthen floors can be mopped and water spills are not a problem.

APPENDIX A ASSESSMENT OF CLAY CONTENT

(Normative)

A1 Field assessment

The earth texture shall be determined on a sample of earth consisting only of mineral particles finer than 2 mm as follows:

(a) Remove any material larger than 2 mm;
(b) Take a sample of earth sufficient to fit comfortably into the palm of the hand;
(c) Moisten the earth with water, a little at a time, and knead the resulting ball of earth until it just fails to stick to the fingers; and
(d) Determine the texture by noting:
    (i) The force required to deform or work the ball of earth
    (ii) The length of flat ribbon, approximately 5 mm thick, that will form when squeezed between thumb and forefinger, and
    (iii) The sandy nature of the ball of earth.

Use Table A.1 to help assign the earth category in A.3.

CA1
As a range of factors in the earth affect its elasticity when worked as described in item (d), the ribbon lengths given in Table A.1 are a guide only. This determination is often called the 'field texture' and is a somewhat subjective judgement. Training and experience are required to produce consistent results.

A2 Laboratory assessment

A detailed laboratory particle-size analysis may be undertaken if considered appropriate. The earth texture is then determined by use of a textural analysis chart or diagram.

CA2
Laboratory assessment of field texture is not normally required if experienced personnel have carried out the field assessment.

A3 Suitability for earth buildings

The following categories, as assessed from Table A.1, can be suitable for the uses recommended, subject to the material passing the testing required by 2.5 and Table 2.1.

Category 1 is not suitable for any form of earth building without the addition and mixing in of more clayey material.

Category 2 can be suitable for rammed earth.

Category 3 can be suitable for rammed earth and cob.

Category 4 can be suitable for cob and adobe.

Category 5 can be suitable for adobe.

Category 6 is not suitable for any form of earth building without the addition of fine gravel or more sandy material for use as adobe or cob.

CA3
This test is based on test E4 from AS/NZS 1547.

Table A.1 Assessment of clay content

Soil category	Classification	Properties	Typical clay % (see Note)
1	Sand	Very little to no coherence; cannot be moulded; single grains stick to fingers	Less than 5
2	Loamy sand	Slight coherence; forms a fragile cast that just bears handling; gives a very short (5 mm) ribbon that breaks easily; discolours the fingers	5–10
	Sandy loam	Forms a cast but will not roll into a coherent ball; individual sand grains can be seen and felt; gives a ribbon 15 mm to 25 mm long	10–20
3	Fine sandy loam	As for sandy loams, except that individual sand grains are not visible, although they can be heard and felt; gives a ribbon 15 mm to 25 mm long	10–20
	Loam	As for sandy loams but cast feels spongy, with no obvious sandiness or silkiness; may feel greasy if much organic matter is present; forms a thick ribbon about 25 mm long	10–25
	Silty loam	As for loams but not spongy; very smooth and silky; will form a very thin ribbon 25 mm long and dries out rapidly	10–25
4	Sandy clay loam	Can be rolled into a ball in which sand grains can be felt; forms a ribbon 25 mm to 40 mm long	20–30
	Fine sandy clay	As for sandy clay loam, except that individual sand grains loam are not visible although they can be heard and felt; forms a ribbon 40 mm to 50 mm long	20–30
	Clay loam	Can be rolled into a ball with a rather spongy feel; slightly plastic; smooth to manipulate; will form a ribbon 40 mm to 50 mm long	25–35
	Silty clay loam	As for clay loams but not spongy; very smooth and silky; will form a ribbon about 40 mm to 50 mm long; dries out rapidly	25–35
5	Sandy clay	Forms a plastic ball in which sand grains can be seen, felt or heard; forms a ribbon 50 mm to 75 mm long	35–45
	Light clay	Smooth plastic ball that can be rolled into a rod; slight resistance to shearing between thumb and forefinger; forms a ribbon 50 mm to 75 mm long	35–40
	Silty clay	As for light clay but very smooth and silky; will form a ribbon about 50 mm to 75 mm long but very fragmentary; dries out rapidly	40–50
6	Medium clay	Smooth plastic ball, handles like plasticine and can be moulded into rods without fracture; some resistance to ribboning; forms a ribbon 75 mm or more long	40–55
	Heavy clay	Smooth plastic ball that handles like stiff plasticine; can be moulded into rods without fracture; firm resistance to ribboning; forms a ribbon 75 mm or more in length	50 or more
NOTE – The typical clay content figures are included for information only.			

APPENDIX B BALL TEST OF CLAY CONTENT FOR MORTAR

(Normative)

B1 Sample preparation

Confirming that an earth sample has sufficient clay content to be suitable for earth mortar should be determined using this test:

(a) Remove any material larger than 2 mm;
(b) Form the material into a small ball between 15 and 20 mm in diameter;
(c) Allow the ball to dry. Check that the ball has not cracked before further testing; and
(d) Attempt to crush the ball by pinching between thumb and forefinger. The pressure should be applied vertically with the thumb at the bottom of the ball.

B2 Acceptance criteria

If the ball resists crushing then the clay content should be adequate to use as a binder in earth building.

Break the ball, with a solid object if necessary, and check that the interior is dry.

If the ball crushes readily then the clay content is too low or the silt content is too high for earth building work.

CB2

This is an additional field test that may also be performed to quickly determine if the clay content in a soil is suitable for unstabilised adobe, cob, LEM, or earth plaster by distinguishing between material with clay in it or material made sticky by wet silt.

APPENDIX C There is no Appendix C

APPENDIX D ASSESSMENT OF DESIGN STRENGTH VALUE FROM TEST RESULTS

(Normative)

D1 Assessment of test results

D1.1 General

This appendix sets out the method for evaluating the characteristic compressive strength or the characteristic flexural tensile strength of a given type of earth wall material, from the results of tests carried out on specimens that are representative of that earth wall.

These principles shall be followed when the characteristic value of any other parameter is to be assessed from test results.

D1.2 Notation

Symbols used in this appendix are listed below.

f = general term for strength used in design representing either f_e or f_{et}

f' = characteristic strength value for the type of masonry represented by the set of specimens f'_e, f'_{et}, or other characteristic strength value

f_{ksp} = the (lower) 5 percentile value for the set of test results, measured or assessed from a relative cumulative frequency distribution of that test data

f_{spa} = suspected abnormal test result

f_{spe} = the average value of all test results for the set under consideration excluding the suspected abnormal result

f_{spl} = the least of the individual results in the set

k_k = characteristic strength factor

n = number of test results in the set used to evaluate f'

X_a = average test result of a series

X_s = standard deviation

$X_1, X_2, \ldots X_i \ldots X_n$ = group of n test results (applicable to methods of D3.1 and D3.2)

x_1, x_2, x_3, x_4 = lowest, second lowest, third lowest, and fourth lowest test results, respectively. (applicable to methods of D4.1 and D4.2)

δ = the coefficient of variation for the set under consideration excluding the suspected abnormal result

ε = dimensionless factor used in formulae of D4.2.

D2 Test specimens

D2.1 Obtaining samples for testing prior to construction

D2.1.1

If the production process has been finalised and early production is underway, testing shall be carried out in accordance with this clause.

D2.1.2

Testing prior to construction shall be carried out from early batches of production bricks, following initial material tests to establish suitability and mixes. Sampling shall be a random selection of bricks from batches at least five times the number of specimens for the required sample.

D2.2 Construction of test specimens prior to production

D2.2.1

Where production plant is not in place test specimens may be constructed to the requirements of this clause.

D2.2.2

Test specimens shall be made from materials that are representative of the earth material or earth bricks where the characteristic strength is to be determined, and, as far as practicable, using similar techniques and standards of construction and under similar conditions to those that are (or will be) applicable for earth walls constructed of that material.

D2.2.3

For construction techniques that do not produce shapes suitable for testing, either samples may be made in special moulds for that purpose or specimens may be cut from fully dried material.

D2.3 Obtaining samples for testing during construction

Specimens shall be selected at random from the various batches of materials that have been produced since the previous sampling. Tensile testing shall be carried out as specimens are collected, compression testing shall be carried out when five specimens are accumulated, at the completion of any stage of the project, or when any change in earth materials is apparent.

D3 Test results

D3.1 Average

The average X_a of a group of test results X_1, X_2, … X_i … X_n, where n is the number of results under consideration after elimination of abnormal results, shall be calculated as:

$$X_a = \frac{X_1 + X_2 + ... X_i ... X_n}{n}$$ ....(Eq. D–1)

D3.2 Standard deviation

The unbiased standard deviation X_s (sample standard deviation as distinct from population standard deviation) of a group of test results X_1, X_2, . . . X_i . . . X_n, where n is the number of results under consideration after elimination of abnormal results in accordance with D3.3, shall be calculated as:

$$X_s = \sqrt{\frac{\Sigma X_i^2 - nX_a^2}{n-1}}$$ .... (Eq. D–2)

D3.3 Abnormal test results

An individual test result that is assessed as being abnormal may be excluded from the set of results for analysis purposes, and the number (n) of results in the set shall be reduced accordingly. If the number (n) is consequently reduced below the minimum number required under Table 2.1, further tests shall be carried out to reach that minimum.

A result shall be assessed as being abnormal only if a specific reason for its abnormality is clearly evident, or if its value (f_{spa}) is outside the range of f_{spe} ±3 δf_{spe}

where the coefficient of variation $$\delta = \frac{X_s}{X_a}$$

Five or more results shall be available before f_{spe} is determined.

D4 Evaluation of characteristic strength

D4.1 Method for five results

Where the results of testing only five specimens are available the following may be used to evaluate the characteristic strength:

$$f' = \left(1 - 1.5\frac{X_s}{X_a}\right)x_1$$ ....(Eq. D–3)

where x_1 is the lowest result.

CD4.1

This is equivalent to n = 5 and k_k = 0.925 (δ = 0.05), k_k = 0.775 (δ = 0.15), k_k = 0.625 (δ = 0.25) which is in good agreement with AS 3700 Appendix B and errs on the conservative side if δ > 0.15.

D4.2 Characteristic value for sample size 10 or greater, and coefficient of variation is not well known

This method shall be used where the coefficient of variation δ has not been established by tests of more than 30 specimens and may be used where the coefficient of variation has been established.

For number of specimens in the sample (*n*) from 10 to 19 the characteristic strength is:

For *n* = 10 to 19

$f' = x_3^{1-\varepsilon} . \left(x_2 . x_1\right)^{\frac{\varepsilon}{2}}$ where ε is given by:

n	10	11	12	13	14	15	16	17	18	19
ε	*3.31*	*3.12*	*2.96*	*2.80*	*2.66*	*2.53*	*2.41*	*2.29*	*2.19*	*2.08*

For *n* = 20 to 29

$f' = x_4^{1-\varepsilon} . \left(x_3 . x_2 . x_1\right)^{\frac{\varepsilon}{3}}$ where ε is given by:

n	20	21	22	23	24	25	26	27	28	29
ε	*2.22*	*2.14*	*2.07*	*2.00*	*1.93*	*1.86*	*1.80*	*1.74*	*1.69*	*1.63*

CD4.2

Example:

For a series of 10 test results for which the lowest three values are 1.45, 1.75, and 1.84. For n = 10 the ε value is 3.31

therefore $f' = x_3^{1-3.31} . \left(x_2 . x_1\right)^{\frac{3.31}{2}} = 1.84^{-2.31} . \left(1.75 \times 1.45\right)^{1.655} = 1.14$

Note that x1, x2, x3, x4 are the lowest, second lowest, third lowest, and fourth lowest test results, respectively (see B2).

This characteristic strength approach is based on the Ofverbeck Power Method: Ofverbeck, P. (1980) Small Sample Control and Structural Safety. Rep.TVBK-3009, Division of Structural Engineering., Lund Institute of Technology, Lund, Sweden, and reported on in Statistical Implications of Methods of Finding Characteristic Strengths R D Hunt and A H Bryant, Journal of Structural Engineering, Vol.122 No.2, Feb. 1996, pp. 202 – 209.

D4.3 Characteristic value where coefficient of variation is known

Where the earth building material has a known coefficient of variation established by 30 or more test results the procedure from Appendix B in AS 3700 shall be used.

D5 Reporting of results

The test report shall include the following information:

(a) Detailed information about the individual specimens tested, including the results of each test;
(b) The characteristic strength value assessed from those test results, in megapascals, and the equation or details of the method used to assess that value; and
(c) Detailed information about any result that is considered to be abnormal, including the reasons for the non-inclusion of any abnormal result in the assessment of the characteristic strength of the earth.

APPENDIX E COMPRESSION TESTS OF EARTH WALL MATERIAL

(Normative)

E1 Sample preparation

E1.1

A minimum sample of five specimens shall be prepared in the same manner as will be used for the material in the wall.

E1.2

Rammed earth samples shall be compacted as per 3.2.2. Rammed earth samples shall be prepared the same way whether the earth is stabilised or unstabilised.

E1.3

Samples of adobe poured earth, in-situ adobe, and cob may be either formed in cylindrical or cubical moulds or sawn from cured material.

E1.4

Mortar and grout shall be tested as cylinders of 2:1 height-to-width ratio.

CE1.4

For strength test samples for the liquid techniques (adobe, grout, in-situ adobe, and poured earth) 200 mm cube samples are recommended.

This size is relatively easy to make to the accuracy required for testing methods, and the large dimensions allow low strengths to be assessed. Small low-strength samples have been found to fail to reach the lower calibration limits of commonly available testing machines.

E2 Testing

E2.1 Age at test

Samples shall be a minimum of 28 days old when tested.

E2.2

Samples shall be loaded in the same direction as will occur in the wall and shall have an aspect ratio of between 1.0 and 2.0.

E2.3

The aspect ratio of the specimen is defined as:

$$A_r = h_s / b_s$$

where h_s is the height of the specimen and

b_s in the smallest lateral dimension of the specimen

E2.4 Aspect ratio factor

The failure stress of each specimen shall be multiplied by the aspect ratio correct factor (k_a) given in Table E.1. Cubical samples shall be treated as having an aspect ratio of 1.0. Linear interpolation shall be used.

E2.5

The characteristic unconfined compressive strength (f'_{uc}) of the sample shall be determined in accordance with Appendix D.

Table E.1 Aspect ratio factor (k_a)

Height to thickness ratio	1.0	2.0
Aspect ratio factor (k_a)	0.88	1.0

E2.6 Test reports

Test reports shall include:

(a) Age;
(b) Dimensions;
(c) Mass;
(d) Material type (rammed earth, adobe, pressed brick, poured earth, or cob);
(e) Test method; and
(f) Orientation (such as, on edge, on flat).

APPENDIX F EARTH BRICK DROP TEST

(Normative)

F1 Brick drop test

A cured earth brick that is not less than 28 days old shall be tested in the following manner:

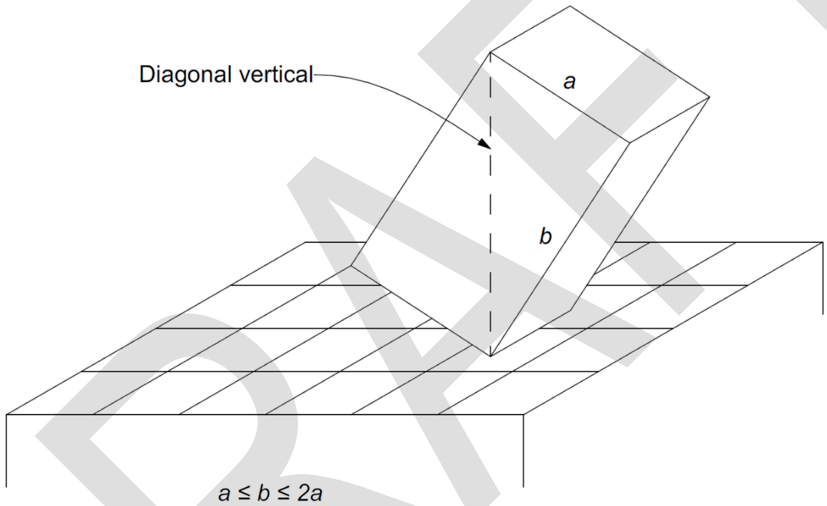
(a) If a brick is longer than 2.0 times its width it shall be sawn or broken to obtain a test specimen that has a length between 1.0 and 2.0 times its width.
(b) It shall be held as shown in Figure F.1 below and dropped with its lowest point 900 mm above the point of impact on to a hard earth or harder, solidly supported surface.

CF1

This test is an adequate field test for any adobe or pressed brick, whether stabilised or unstabilised.

F2 Pass criteria

The brick shall pass if it does not break into approximately equally sized pieces, nor shall there be missing from the largest remaining piece 100 mm or greater from any corner.



$a \leq b \leq 2a$

NOTE -

If $b>2a$, cut brick in half before testing

Figure F.1 – Orientation of earth brick prior to dropping

APPENDIX G FLEXURAL TENSILE STRENGTH TEST

(Normative)

G1 Stacked bricks method

> ***CG1***
>
> *A simple field test procedure is shown below.*

G1.1 Equipment

The test is to be undertaken on firm level ground or on a firm concrete or wooden surface. The test is to be set up as shown in figure G.1 using 10 mm thick sand beds under each load point to distribute loads across the full brick width. The timber batten supporting the edge of the brick stack shall be placed directly above the support for the brick being tested. The load stack is offset with the dimension $x \approx 0.04$ m (40 mm) to prevent the load bricks toppling prior to failure. The brick being tested shall be a minimum of 350 mm long. For test bricks shorter than 350 mm the method of G2 is to be used. The length between supports of the brick being tested shall be more than twice its depth.

G1.2 Procedure

G1.2.1

The weight (W) of the bricks is determined by taking the average of the weights of 10 bricks that have been manufactured in an identical manner. The weights shall be determined to an accuracy of 0.5 kg and any brick of the 10 that varies by more than 5% from the average shall be discounted and the weight of another brick substituted until these criteria are met.

G1.2.2

Before additional bricks are placed on the first load brick, measurements shall be taken of the dimensions b, d, ℓ, L, and x to an accuracy of 1.0 mm.

G1.2.3

The test load is applied by stacking bricks one at a time until the failure in bending is reached.

> ***CG1.2.3 Caution***
>
> *The stack of load bricks is capable of causing severe injury if it topples following brick failure.*

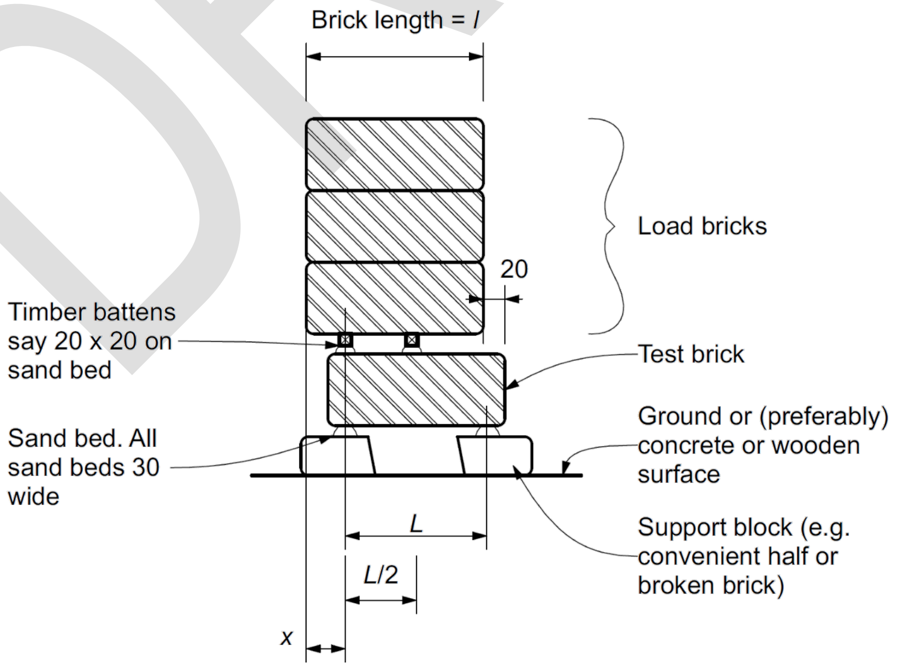


Figure G.1 – Stacked bricks rupture test

G1.3 Results

The flexural tensile strength (modulus of rupture) (f_{et}) is calculated from the formula:

$$f_{et} = \frac{0.015\ nWL}{bd^2} \times \frac{\ell - 2x}{L} \text{ kPa} \quad \text{(Eq. G-1)}$$

where

b = breadth of test brick (m)

B = brick length (m)

d = depth of test brick (m)

L = length between centres of test brick support (m)

n = number of load bricks at failure

W = weight of each load brick (kg)

x = offset of load bricks support from end of load stack (m)

ℓ = length of load bricks (m)

The result shall be recorded to the nearest 10 kPa.

CG1.3

The above formula is derived assuming that 100 kg weighs 1 kilo newton.

The factor $\frac{\ell - 2x}{L}$ *is to compensate for load offset.*

The equivalent laboratory method should use two 50 mm steel tubes to support the brick and a third tube to apply the test load. This is the modulus of rupture test as described in the USA Uniform Building Code 1982 (International Conference of Building Officials, Whittier, California), Section 24. 1409. See figure G.2.

In this test

$$f_{et} = \frac{3}{2} \times \frac{nW(\ell - 2x)}{bd^2} \text{ kPa if } W \text{ is in kN}$$

$$f_{et} = \frac{3}{200} \times \frac{nW(\ell - 2x)}{bd^2} \text{ kPa if } W \text{ is in kg}$$

G2 Lever method

G2.1 Equipment

G2.1.1

An apparatus based on the principles of figure G.2 shall be used.

CG2.1.1

A common test brick is 130 mm wide, 280 mm long. Using 20 mm battens, this would give L = 240 mm. The load (Q) could be 60 kg or higher.

Other similar dimensions or brick sizes can be used if desired.

Testing a full-width 300 mm brick will require twice the load and stronger, lever arm, fixings, and bench.

G2.1.2

The length (*L*) between supports of the brick being tested shall be more than twice its depth.

CG2.1.2

For a 280 mm long brick with L = 240 mm, the maximum thickness can be 120 mm.

G2.2 Procedure

G2.2.1

The dimensions b, d, L_1 , L_2, and L shall be measured to an accuracy of 1.0 mm.

G2.2.2

The lever arm shall be within 20 mm of horizontal when the load is applied. Load shall be added gradually until the brick fails.

G2.2.3

The beam weight G and the load at failure Q shall be determined to an accuracy of 0.2 kg.

G2.3 Results

The following formula shall be used to calculate the flexural tensile strength f_{et}:

$$f_{et} = \frac{L_1}{L_2} \text{x} \frac{0.015\text{x}\left(Q + \frac{G}{2}\right)L}{bd^2} \qquad \text{(Eq. G-2)}$$

where

L_1 , L_2 = as defined in figure G.2

Q = the test failure load (kg)

G = the weight of the beam (kg)

Other symbols as defined in G1.3.

CG2.3

As an example where:

L = 0.240 m

L_1 = 2.2 m

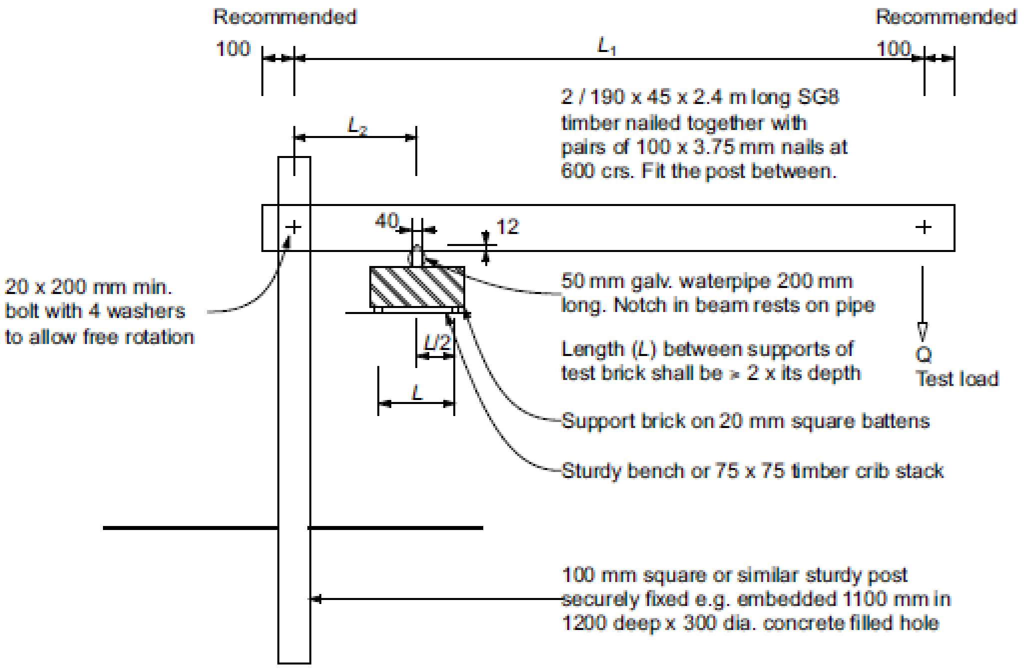
L_2 = 0.4 m

b = 0.130 m

d = 0.120 m

Gives

$$fet = 10.6\left(Q + \frac{G}{2}\right) kPa$$



NOTE -
(1) Other similar dimensions or brick sizes can be used if desired.
(2) Testing a whole brick 300 mm square will require twice the load and stringer beam, fixings, table hold-down.
(3) The outer end of the lever shall be horizontal when the load is applied.

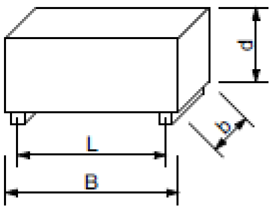


Figure G.2 – Lever rupture test

APPENDIX H SHRINKAGE TEST

(Normative)

H1 Shrinkage test equipment

H1.1

Open top shrinkage boxes can be made from steel or wood but must be able to resist ramming pressure if used to test rammed earth samples. The internal dimensions of each shrinkage box is 600 mm long × 50 mm wide × 50 mm high. Wooden boxes shall be painted or oiled to prevent moisture take up from the sample.

H1.2

The ends of the box shall be square and smooth. Metal shims may be added if necessary to ensure a smooth end surface for measuring against.

H1.3

The sides and bottom of the cavity shall be lined with two layers of newsprint to stop the material sticking to the apparatus.

CH1.3

Single boxes may be made, or multiple boxes made side by side.

H2 Procedure

H2.1

To test adobe, cob, unstabilised mortar, or LEM, take a sample of a proposed mix that has been prepared in the same manner as that to be used for construction and place the sample into the shrinkage box without any holes or gaps and allow to air dry until dry for a minimum of 28 days. Ensure the sample is dry before taking measurements.

H2.2

To test rammed earth shrinkage, make up a sample of mix with the same percentage of material and at the same moisture content as would normally be placed in a wall. Ram it firmly into the shrinkage box using a suitable hand or mechanical rammer.

For testing a sample of poured earth, or in-situ adobe, make up a mix at optimum moisture content for workability for the application proposed, and place the sample into the shrinkage box without any holes or gaps.

Cure it moist for seven days by covering the sample with plastic, then air dry out of the direct sun for a further 21 days.

H2.3

For samples containing lime, moist cure as above for 21 days before air drying for seven days. Ensure the sample is dry before taking measurements.

H2.4

The smoother the surface of the sample the easier it is to see cracks and assess shrinkage.

H3 Calculation of results

Measure the shrinkage using mechanic's feeler gauges after a minimum of 28 days. If the sample is cracked along its length push the sample together from each end. Measure the shrinkage at each end and add the results.

For required shrinkage results see Table 2.1.

APPENDIX I RAMMED EARTH MIX MOISTURE CONTENT DROP TEST

(Normative)

I1 Moisture content drop test method

A handful of the mixture as mixed ready to be placed between the shutters (that is with all components, such as earth, water, and cement fully mixed) shall be squeezed once in the palm of one hand, held up to shoulder height, and dropped onto any hard flat surface.

CI1

This test is as outlined in CSIRO Australia Publication Bulletin 5 Earth Wall-Construction Fourth Edition by G F Middleton, revised by L M Schneider in 1987.

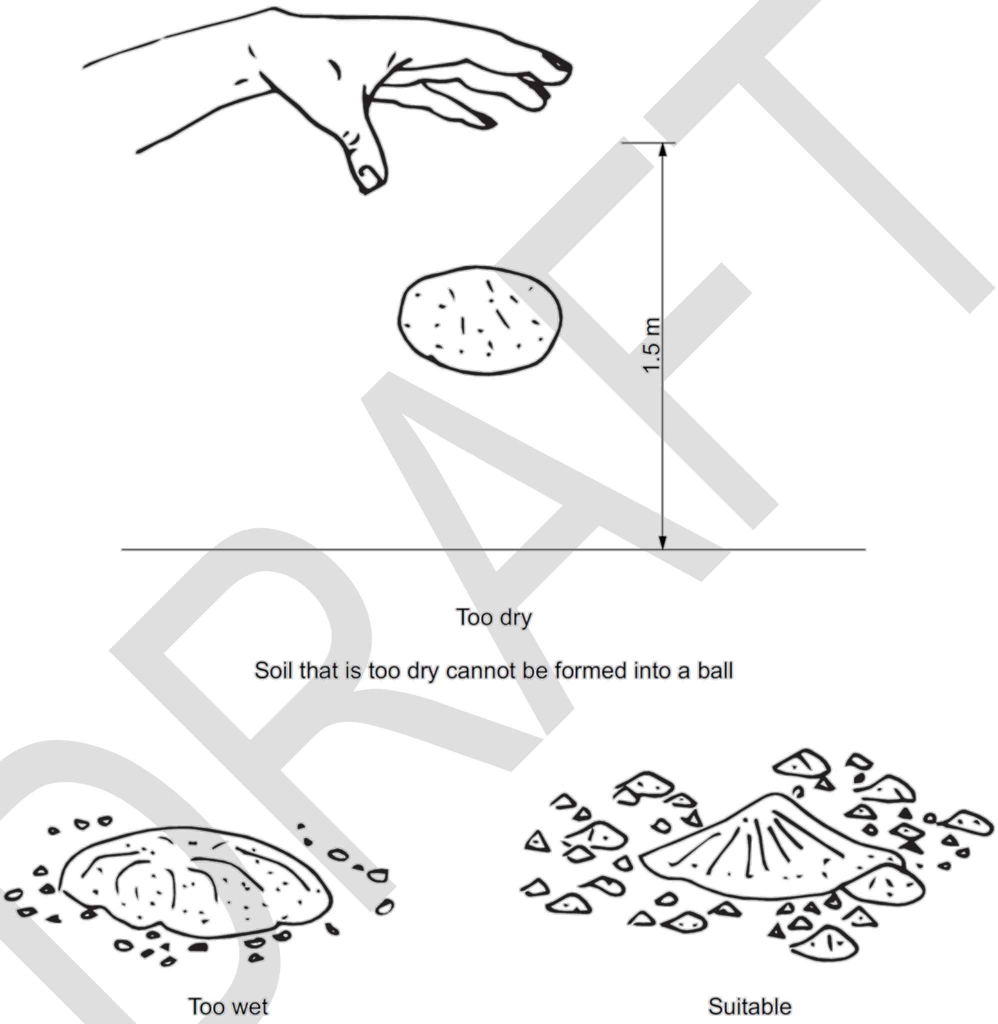


Figure I.1 – Moisture content for rammed earth

I2 Acceptance criteria

If the handful shatters into a star-shaped pattern of powder, then the mix is too dry. If it shatters or breaks into a star-shaped smaller pattern containing several lumps, then the moisture content is satisfactory. If the lump merely breaks into two or three deformed small pieces, or stays as one deformed soggy piece, then the moisture content is too high.

CI2

A hard surface can be timber planking, concrete, or steel sheet.

A material at a suitable moisture content for ramming will not stick to the rammer, nor will it 'heave' when it is rammed – both signs that the moisture content is too high.

APPENDIX J WET/DRY APPRAISAL TEST

(Normative)

J1 Elimination of unacceptable soils

This cyclic wet/dry test is to eliminate reactive soils and soils or earth/stabiliser mixes with unacceptable properties.

CJ1

This test is to eliminate unsuitable earth building materials that may be able to pass strength tests and other durability tests but, because of the clay minerals present or because of inappropriate mix constitution or manufacturing techniques, are likely to fail in service after repeated wetting and drying. The test simulates a number of wetting and drying cycles.

J2 Equipment

The following equipment is required:

(a) A dish for the sample to be soaked in, which shall have a plan area at least 1.5 times larger than the face being soaked; and
(b) Three $2 coins.

CJ2

Materials that have passed this test have been known to fail where weather protection in clause 2.7 of NZS 4299 is absent.

J3 Procedure

J3.1

Two identical sample bricks are selected. One, the reference brick, is set aside. Alternatively, two opposite faces of the same brick may be used – one for testing, one for reference.

J3.2

Support the sample approximately 2 mm above the base of the dish by three $2 coins placed under it. Soak one face of the sample in water of 10 mm initial depth for the following periods:

(a) 4 minutes for materials that are required to have an erodibility index of 1;
(b) 2 minutes for materials that are required to have an erodibility index of 2;
(c) 1 minute for materials that are required to have an erodibility index of 3; or
(d) 0.5 minutes for materials that are required to have an erodibility index of 4.

The face to be soaked shall be a face that is intended to be a vertical face when the brick is incorporated into a wall.

CJ3.2

The soaked face will normally be the longest side face of a brick.

J3.3

Air dry the sample. The sample is to be dried for one day or until the colour and appearance of the tested brick matches that of the reference brick indicating that drying is complete, whichever is the longer. Accelerated drying may be carried out in an oven at temperatures of less than 70°C until the colour and appearance matches that of the reference brick or one day whichever is the shorter.

J3.4

Examine and record the condition of the soaked face at the end of each drying operation. Note particularly any of the following conditions:

(a) Crazing-type crack patterns;
(b) Star-type crack patterns;

(c) Local swelling;
(d) Local pitting in at least five locations;
(e) Local or general fretting, that is loss of layers of earth either upon wetting or after drying;
(f) Penetration of the water, as indicated visually on the outer surfaces of the brick, by more than 70% of the brick width;
(g) The loss of fragments of the brick larger than 50 mm greatest dimension, except that part of fragments that come from within 50 mm of the edges of the brick shall not be included; or
(h) Efflorescence, that is powdery crystals, on the brick surface. It is usually white.

J3.5

Repeat steps J3.2 to J3.4 for a total of six cycles. The same face shall be soaked in each cycle.

J3.6

On the sixth cycle the sample is to be dried for two days or until the colour and appearance of the tested brick matches that of the reference brick indicating that drying is complete, whichever is the longer.

J4 Acceptance criteria

The earth or earth mix represented by the sample is acceptable if, during or at the completion of the procedure detailed in J3, there has been no appearance of any of the conditions noted in J3.4.

NOTE – The use of surface coatings to improve the performance of material that fails the wet/dry appraisal test is outside the scope of this standard.

APPENDIX K EROSION TEST (PRESSURE SPRAY METHOD)

(Normative)

K1 Pressure spray test

The test consists of spraying the face of a prepared sample of the earth for a period of one hour or until the specimen is penetrated.

CK1

The test is an empirical one developed by the former National Building Technology Centre now CSIRO (Commonwealth Scientific and Industrial Research Organisation – Australia).

K2 Procedure

K2.1

The components of the equipment are shown in Figure K.1 and Figure K.2.

K2.2

The specimen shall be cured a minimum of 28 days before testing.

The exposed section of the specimen is subjected to the standard spray for one hour or until the specimen is eroded through. The test is interrupted at 15-minute intervals and the depth of erosion recorded.

K3 Results

K3.1 Determining erodibility index

The maximum depth of erosion of the deepest pit in one hour is measured in millimetres with a 10 mm diameter flat-ended rod. When the spray bores a hole right through the specimen in less than hour the rate of erosion is obtained by dividing the thickness of the specimen by the time taken for full penetration to occur. The erodibility index shall be determined by reference to Table K.1.

Table K.1 Erodibility indices from pressure spray erosion test

Depth of erosion *D* (mm/hr)	**Erodibility index (EI)**	**Depth of penetration (mm)**
$0 \le D < 20$	*1*	*60*
$20 \le D < 50$	*2*	*80*
$50 \le D < 90$	*3*	*100*
$90 \le D < 120$	*4*	*120*
$D \le 120$	*5*	*NA*

K3.2 Erodibility improvement by stabilisation

The earth wall material erodibility index may be improved by stabilisation of the earth wall material by the addition of cement or lime or by application of lime plaster. Surface coatings may be used but shall only improve the durability index by a maximum of one point. The improved or coated earth wall material shall be retested using the spray erosion test (Appendix K) or the drip test (Appendix L) where appropriate to determine the improved earth wall erodibility index.

K4 Penetration of moisture

After completion of the spray test, penetration of moisture is measured by breaking the specimen across the point where erosion is deepest and inspecting the break surface if the sample is more than 120 mm thick.

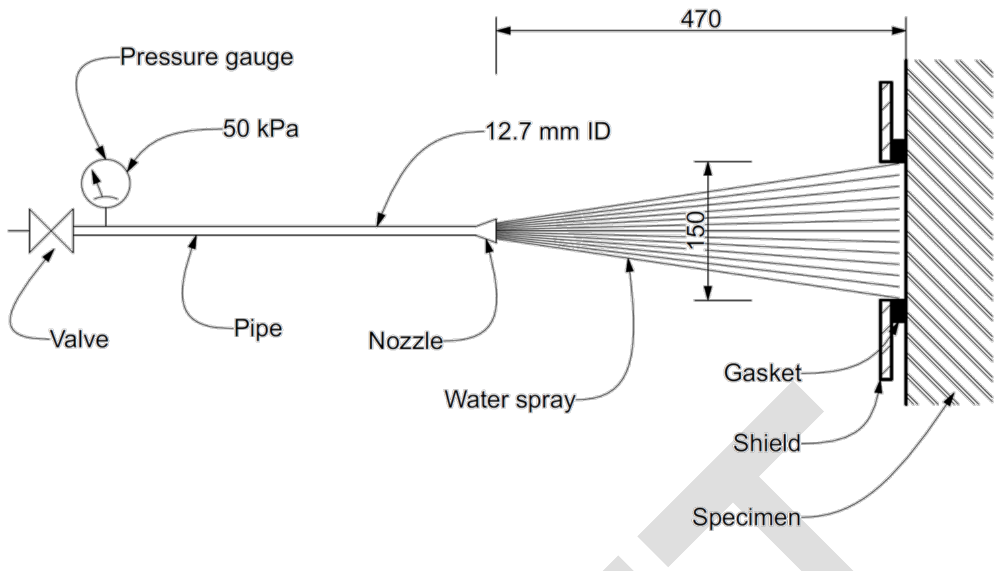


Figure K.1 – Pressure spray test general arrangement

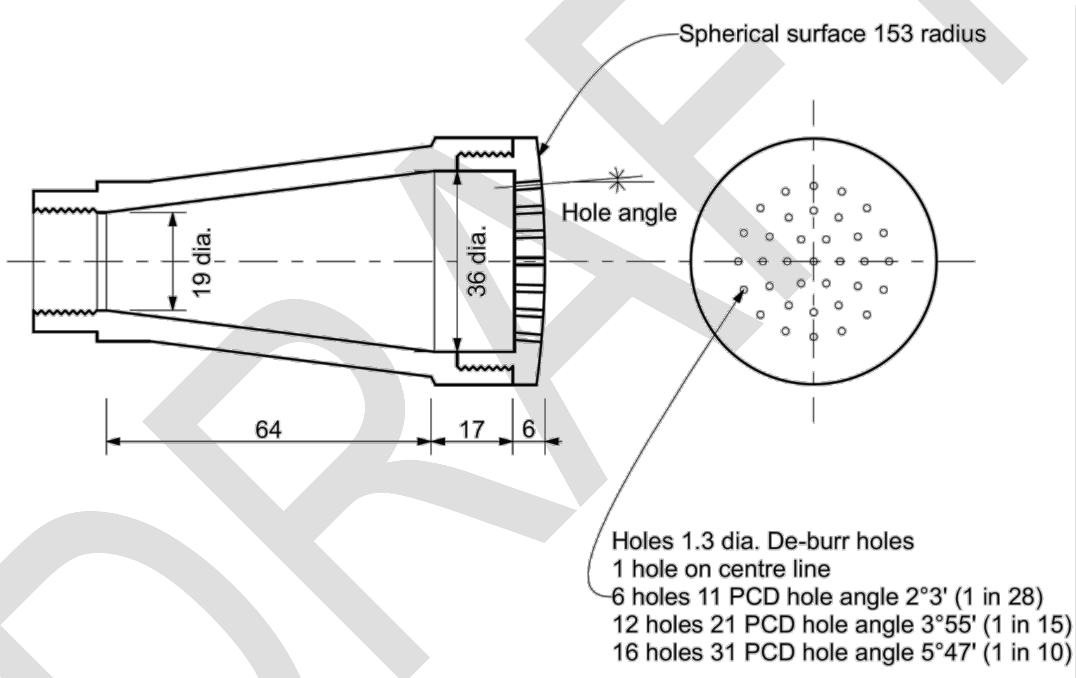


Figure K.2 – Pressure spray test nozzle

K5 Cyclic wet/dry appraisal test

The cyclic wet and dry appraisal test as specified in Appendix J is required to eliminate reactive and dispersive soils.

K6 Surface coatings

The sample shall be tested without any surface coating (see 8.1.3, 8.2.3, and 8.2.4).

APPENDIX L DRIP EROSION TEST

(Normative)

L1 Drip erosion test

L1.1

For rammed earth testing, bricks 300 mm square by 125 mm thick shall be made by ramming earth on edge in a mould with these internal dimensions.

L1.2

Cob or poured earth samples can be made by casting bricks in a similar sized mould.

The person making the test shall determine which face to test. However, it is generally accepted that the 'off-form' side of the face of the wall/sample facing toward the weather is to be tested.

L1.3

Samples may be cut from existing walls of any dimension and tested with the drip onto an uncut wall face.

L1.4

The specimen shall be cured a minimum of 28 days before testing.

L1.5

This test must be carried out in a location sheltered from wind and direct sun.

CL1.5

Other convenient mould or rammed earth brick sizes may be used if desired.

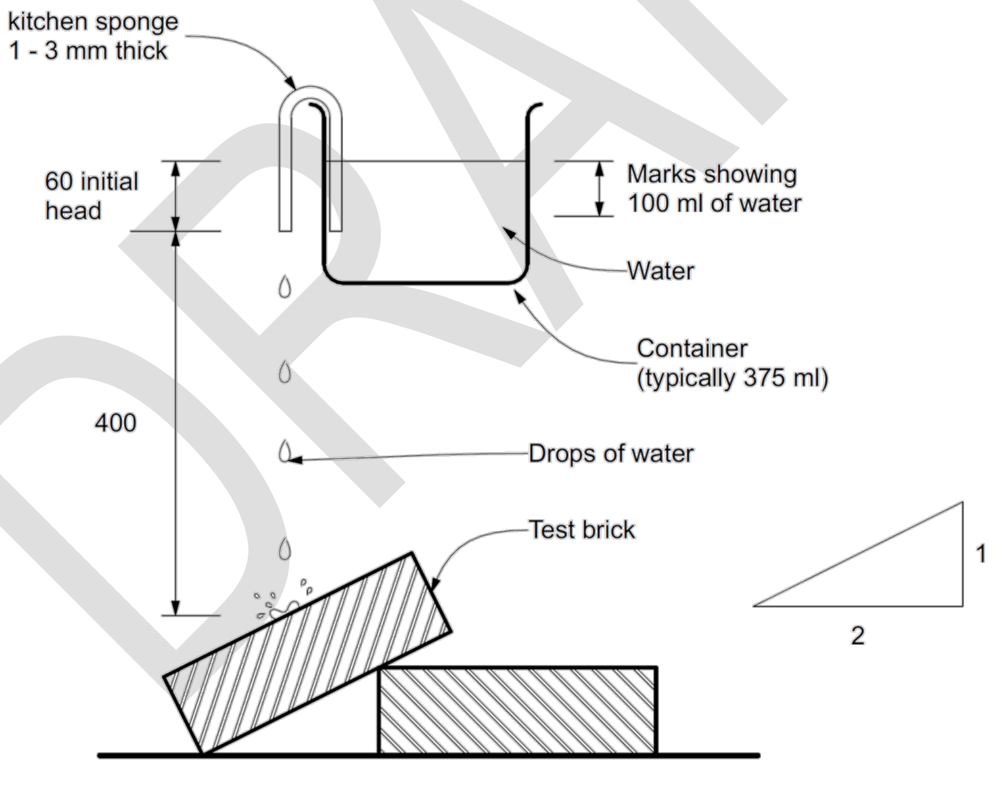


Figure L.1 – Drip erosion test method erosion test configuration

L1.6

The wick is a 20 mm wide strip cut from a kitchen sponge between 1 mm and 3 mm thick, and long enough to transfer water over the rim of the container to maintain a series of drips.

L2 Sample bricks

For adobe or pressed bricks, randomly selected bricks shall be used.

L3 MEASUREMENT OF PIT DEPTH

The pit depth is to be measured with a cylindrical probe with an end diameter of 3.15 mm.

The method is as follows:

(a) Allow 100 ml of water to drop 400 mm onto the sloped face of the test brick.
(b) Time taken for 100 ml to drip from the container is to be 20 minutes minimum to 60 minutes maximum.

CL3

The pit depth probe may be made from a 3.15 mm diameter ungalvanised nail filed to a square end.

L4 Cyclic wet/dry appraisal test

The cyclic wet/dry appraisal test as specified in Appendix J is required to eliminate reactive and dispersive earths.

L5 Surface coatings

The sample shall be tested without any surface coating (see K6, 8.1.3, 8.2.3 and 8.2.4).

L6 Moisture penetration

L6.1

Immediately after completion of the drip test, penetration of moisture is measured by breaking the specimen across the point where erosion is deepest and inspecting the break surface if the brick is thicker than 120 mm.

L6.2

If the maximum depth of penetration is less than 120 mm, the sample passes the test. If the penetration depth is equal to or greater than 120 mm, the sample fails.

L6.3

Dry the sample after testing and check for the conditions noted in Appendix J3.4. The appearance of these conditions is grounds for rejection of the material.

L7 Results

The erodibility index shall be determined by reference to Table L.1 below. An erodibility index of 1 shall be determined only by use of the pressure spray erosion test given in Appendix K.

Table L.1 Erodibility indices from the drip erosion test method erosion test

Property	Criterion	Erodibility index
Pit depth, *D* (mm)	$0 < D < 5$ $5 \le D < 10$ $10 \le D < 15$ $D \ge 15$	*2* *3* *4* *5 (fail)*

CL7 Acknowledgement

This test was developed by Peter Yttrup and students at Deakin University, Geelong, Victoria, Australia.

APPENDIX M DENSITY TEST

M1 Measuring dimensions and mass

(Normative)

M1.1 General

The density of earth building materials is to be measured as required by Table 2.1.

CM1.1

The density of earthen materials is also needed for determination of thermal conductivity in accordance with NZS 4299 clause 2.8.

M1.2 Sample preparation

The test is to be carried out on a block prepared either in a mould or sawn from dried material.

The minimum dimension of any side of the test block is to be 100 mm.

Minor damage to the corners as shown in the corner detail on Figure M.1 shall be such that the maximum dimension the damage given by L_c or H_c or W_c is 25 mm.

A straight edge across any surface for the block in any alignment as shown in Figure M.2, shall not have a gap (d) between the straight edge and the block surface at any point greater than 4 mm.

The block shall be dried to a moisture content of less than 20%.

CM1.2

Sheltered outdoor drying to less than 20% moisture content usually takes 28 days – additional time allowance should be made in humid or cold weather. In service, earth walls will generally be less than 10% moisture content. Tests on earth wall material with higher moisture contents will give higher density and lower strength which may result in needing to design for greater seismic loads. Higher moisture content will also give lower calculated insulation values.

M1.3 Measurement

The dimensions H_1 to H_8, L_1 to L_3, W_1 to W_3 shown, in Figure M.1 shall be measured to an accuracy of ± 1 mm.

The mass (M) shall be measured to three significant figures by scales with an accuracy of ± 3%.

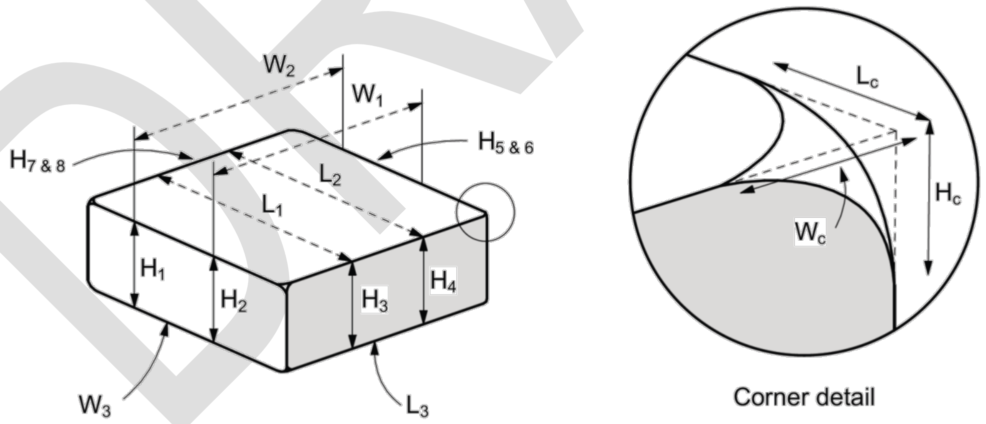


Figure M.1 – Measurement of block for density measurement

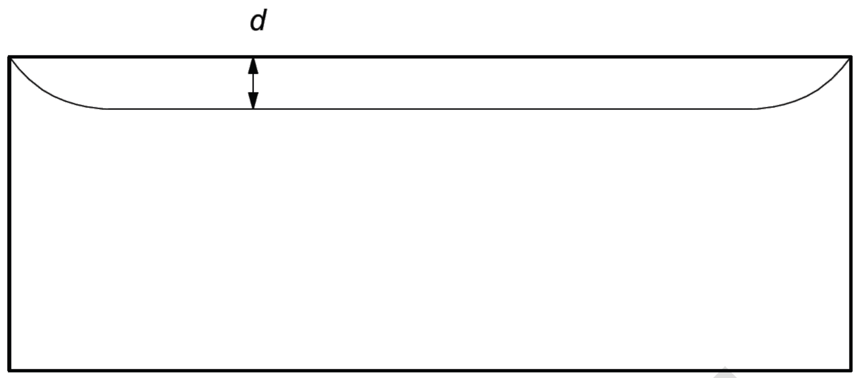


Figure M.2 – Density test block with raised top edges

M1.4 Density calculation

The earth building material density ρ is given by:

$$\rho = \frac{M}{H_{av} \ x \ L_{av} \ x \ W_{av}} x \ 10^9 \quad \text{in kg/m}^3 \text{ ....(Eq. M-1)}$$

where

M = the mass in kg

H_{av} = the average of the block height measurements in mm

L_{av} = the average of the block length measurements in mm

W_{av} = the average of the block width measurements in mm

Where the measurements of each of H_i, L_i, and W_i are within 2% for each variable, the average of two readings may be used.

APPENDIX N FLEXURAL TENSILE STRENGTH BY BOND WRENCH TEST

(Normative)

N1 General

This section sets out the method for constructing and testing specimens for determining the flexural strength of masonry perpendicular to bed joints by the bond wrench test method.

The apparatus used in the bond wrench test shall comply with clause N1.3 and the flexural bond strength shall be calculated in accordance with clause N1.6.

If the apparatus is in the form illustrated schematically in figure N.1 it shall be set up and calibrated in accordance with clause N1.4 and the test shall be carried out in accordance with clause N1.5. Similar calibration and test procedures shall apply when other forms of apparatus are used to achieve the same objectives.

N2 Number of specimens per sample

The number of flexural test specimens shall be five or more. If there is damage, then specimens shall be reconstructed and no less than four shall be tested.

N2.1 Laying procedure

Specimens shall be made of stack bonded piers two bricks high made as group in a similar way to the proposed wall. The laying procedure is:

(a) The first course of units to be laid on a firm flat surface leaving a gap between bricks of at least 20 mm;
(b) Place a mortar bed on all units using wetting procedures and full bedding width and depth as specified and designed for the wall;
(c) Wait the typical lay period and place the next course taking care to align faces; and
(d) On the completion of laying, tool or rake the joints in a manner identical with that proposed for the wall.

N2.2 Age at test

Testing shall be carried out between 28 and 40-days' drying time or longer if the drying conditions are poor.

N2.3 Transportation

Specimens shall not be transported to the testing place until within 3 days of the testing time.

N3 Apparatus

The apparatus for the bond wrench test shall include the following:

(a) A bond wrench, which applies a bending moment to the joint to be tested in the specimen. Before test loads are applied, the wrench shall be of such a mass and proportions that the flexural stresses imposed by the bond wrench on the tested joint shall not exceed 0.04 MPa when calculated in accordance with clause N1.6;

> ***CN1.3(a)***
>
> *To comply with this requirement the maximum mass and proportions of the bond wrench will not exceed 28 kg for a standard 280 mm × 280 mm adobe brick and 14 kg for a half brick.*

(b) If a brick on an existing earth masonry wall or on top of a wall segment is being tested, then the remainder of the wall needs to be fully supported and restrained to prevent damage or collapse; and
(c) Loads applied to the wrench need to be measured to an accuracy of within +/- 0.03 kg.

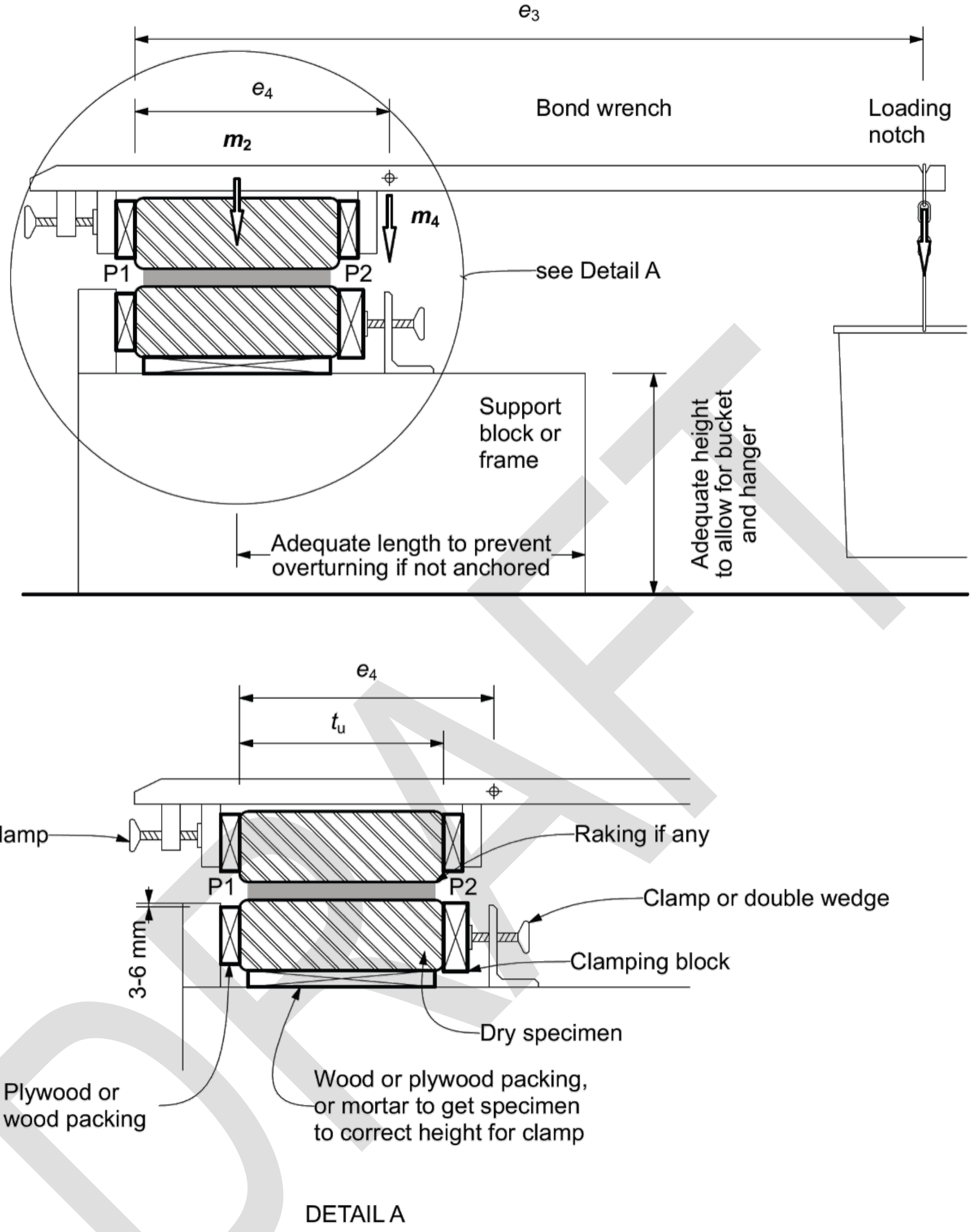


Figure N.1 – Bond wrench, specimen, and arrangement

N4 Set-up measurements and calibration

The bond wrench (similar to Figure N.1) shall be calibrated as follows. The clamp needs to be opened with inside faces aligned to the width brick specimen plus the thicknesses of upper packing P1 and P2.

(a) Determine the mass of upper packing sawn timber or plywood, match P1 to be similar to P2 in size and mass.

(b) Determine the mass of the bond wrench (m_4) to within +/- 50 g (0.05 kg)

(c) Determine the distance from the inside edge of the outer clamp face to the loading notch (e_3) to within +/- 2 mm.

(d) Determine the distance from the inside edge of the outer clamp face to the centre of gravity of the wrench (e_4) to within +/- 2 mm.

CN4

Mass measurements need to be accurate for the bond wrench test. Medium-quality digital hanging scales capable of 50 kg that read to +/-20 g can be used but will need to be calibrated by using a number of masses validated by smaller and more accurate scales and then determining exact measurements through the range. Three kg digital kitchen scales can be checked to measure 1 kg (Precisely 1.00 litre of water) then that weight replaced with another similar mass and the 1 kg mass added again and should measure 2 kg to within +/- 2 g that is 1.997 to 2.003 kg. If the scales are measuring consistently, then five 2 kg bags of sand can be accumulated and added to the measuring scales calibrated at 10 kg intervals with the adjustments recorded and applied to the measured values.

N5 Test procedure

The procedure for testing each specimen using the bond wrench method shall be as follows:

(a) Install the specimen into the test rig and pack beneath the specimen to ensure that the mortar joint to be tested is 3–6 mm above the surface of any clamping. Securely retain the lower brick of the specimen to the support or base frame by clamping or wedging to support greater than 90% of the length of the lower brick. The clamping block shall be a minimum of 35 mm thick and stiff enough to restrain the full length. If the backing block is full length steel, then use thin plywood or sawn timber packers to prevent surface crushing.
If the support or base frame is not fixed to the floor, then add counterbalancing weights to ensure stability when fully loaded;

(b) Clamp the bond wrench to the top brick of the specimen securing packing timbers P1 and P2 and adjust the wrench so the arm is horizontal;

(c) Suspend the empty loading container on the loading notch of the wrench with the bottom of the container not more than 100 mm above the floor (or ground) level. Load the container at an even rate of between 10 kg/min to 15 kg/min using dry sand, or other appropriate material, until the upper part of the specimen separates from the lower restrained part;

(d) Determine the following (see Figure N.1):
    (i) Mass of the container, contents and supporting system together (m_3) to within +/- 50 g (0.05 kg)
    (ii) Mass of the top brick and any mortar adhering to it to within +/- 50 g
    (iii) Width (t_u) of the top masonry unit to within +/-2 mm
    (iv) Dimensions of the bed joint that is tested, to within +/-2 mm, to enable the bedded area and section modulus of the joint to be calculated.

N6 Calculation of flexural bond strength

The flexural bond strength shall be:

$$f_{sp} = M_{sp}/Z_d - F_{sp}/A_d \quad \text{(Eq. N-1)}$$

where

f_{sp} = flexural strength of specimens in megapascals (MPa)

M_{sp} = bending moment about the centroid of the bedded area of the tested joint, in newton millimetres (N mm)

F_{sp} = total compressive force on the bedded area of the tested joint in newtons (N)

A_d = the design cross sectional area [$t_u \times b$]

t_u = the width of a masonry unit in a wall [t_b bed thickness if failure through mortar bed]

Z_d = section modulus of the cross-section based on the bedded area of the perpend joints

n = number of test results in the set

f_{spl} = the least of the individual test results in the set

f_{spm} = mean value of a set of specimen test results

f'_{mt} = characteristic flexural tensile strength of masonry specimens

t_b = wall thickness at mortar bed accounting for raking otherwise t_u

b = brick breadth (perpendicular to t_b at mortar bed interface)

A_d = $t_b\ b$

Z_d = $b\ t_b^2/6$

m_2, m_3, m_4 in kg

M_{sp} = $m_3 \times 9.8\ (e_3 - t_u/2 - t_{P1}) + m_4 \times 9.8\ (e_4 - t_u/2)$

F_{sp} = $(m_2 + m_3 + m_4 + m_{P1} + m_{P2}) \times 9.8$

The characteristic flexural tensile strength (f'_{mt}) may be calculated by the methods of D4.1 for five tests results or by the methods of D4.2 or D4.3 where additional results are available.

CN6 Example calculation

	e_3 (mm)	e_4 (mm)	m_4 wrench (kg)	t_u (mm)	$P_1 + P_2$ (kg)
	1087	288	3.23	287	1.55 + 1.30
Test measure	m_3 (kg)	t_b (mm)	Breadth b (mm)	m_2 (kg)	
	25.64	287	440	16.88	
Calculate	A_d (mm^2)	Z_d (mm^3 x10^3)	M_{sp} (Nmm x10^3)	F_{sp} (N)	f_{sp} (MPa)
	126,280	6040	242.2	477	0.0363

M_{sp} = $m_3 \times 9.8\ (e_3 - t_u/2) + m_4 \times 9.8\ (e_4 - t_u/2)$

= $25.64 \times 9.81(1087 – 143.5) + 3.23 \times 9.81(288 - 143.5)$ [237,317 + 4579]

= 242,173 Nmm

Z_d = $440 \times 2872/6$

= 6,040,393

F_{sp} = $(m_2 + m_3 + m_4 + m_{P1} + m_{P2}) \times 9.81$

= $(16.88 + 25.64 + 3.23 + 1.55 + 1.30) \times 9.81$ = [48.6 × 9.81]

= 476.8

f_{sp} = $M_{sp}/Z_d - F_{sp}/A_d$

= 242,200/6,040,000 – 476.8/126,280

= 0.0400 - 0.00378

= 0.0363 MPa

= 36 kPa

APPENDIX O DETERMINATION OF STRENGTH OF EARTH BRICK PIERS

(Normative)

O1

Piers shall be made up of an even number of bricks and shall have an aspect ratio of between 3 and 5.

The aspect ratio of the specimen is defined in E2.3.

O2

Pier tests shall be as per Appendix 2B of NZS 4210. If samples are being cut from existing rammed earth walls then non-standard sizes may be cut and tested. It is acknowledged that accurate cutting even with subsequent trimming may give unusual sizes which nevertheless can be tested and validly used to gain approval under this standard.

O3

Pier tests are required on projects of 10,000 bricks or 450 m^2 wall area (approximately 500 m^2 floor area) or larger or building projects of importance levels 3 and 4 as defined in AS/NZS 1170.0.

APPENDIX P PRESSED BRICK LAYERING TEST

(Normative)

P1 Sampling

Out of every 2500 bricks a sample of either five or three, in accordance with Table 2.1, shall be taken. The sample bricks shall be dry sawn in half perpendicular to the plane of compression.

P2 Examination

The sawn faces shall be examined for layering or for evidence of uneven mixing. The presence of either or both indicates an unacceptable brick.

CP2

Variations of colour or texture between one part of the sawn surface and another or the obvious layering of material within the brick indicates unacceptable mixing.

P3 Acceptance criteria

The whole 2500 brick batch shall be condemned for exterior use if the total number of unacceptable bricks is more than one.

