NEW ZEALAND

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NZS 4298 (1998): Materials and workmanship for earth buildings [Building Code Compliance Document E2 (AS2)]

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NZS 4298:1998
Incorporating Amendment No. 1

MATERIALS AND WORKMANSHIP FOR EARTH BUILDINGS

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COMMITTEE REPRESENTATION

This Standard was prepared by the New Zealand-only sub-committee, BD/83/2, of the Joint Australia/New Zealand Technical Committee BD/83 Earth Buildings for the Standards Council established under the Standards Act 1988. Sub-committee BD/6/2 consisted of:

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Standards New Zealand wishes to acknowledge the approval received from the CSIRO, Australia, to publish drawings of the pressure spray test method in Appendix D.

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AMENDMENTS

No	*Date of issue*	*Description*	*Entered by, and date*
1	June 2000	Corrects a cross reference and eliminates a contradiction between Table 2.1 and Appendix N	Incorporated in this reprint

NOTES

CONTENTS PAGE

Contents continued overleaf

Appendix

Figure

Table

RELATED DOCUMENTS

Reference is made in this Standard to the following:

NEW ZEALAND STANDARDS

NZS 3109:1997 Concrete construction

NZS 3124:1987 Specification for concrete construction for minor works

NZS 3402:1989 Steel bars for the reinforcement of concrete

NZS 3421:1975 Specification for hard drawn mild steel wire for concrete reinforcement

NZS 3603:1993 Timber Structures Standard

NZS 3604:1999 Timber frame building construction

NZS 4203:1992 General structural design and design loadings for buildings

NZS 4210:1989 Code of practice for masonry construction: materials and workmanship

NZMP 4212:1998 Glossary of building terms

NZS 4297:1998 Engineering design of earth buildings

NZS 4299:1998 Earth buildings not requiring specific design

NZS 4402:- – - - Methods of testing soils for civil engineering purposes
Part 4, Section 1.1:1986 Test 4.1.1 New Zealand standard compaction test

AUSTRALIAN STANDARD

AS 3700-1988 Masonry in buildings

BRITISH STANDARD

BS EN ISO 10319 Geotextiles. Wide width tensile test

OTHER PUBLICATIONS

New Zealand Building Industry Authority, 1992, New Zealand Building Code.

CSIRO Australia (Division of Building, Construction and Engineering). Bulletin 5: Earth-wall construction (4th edition, 1987).

Building Research Association of New Zealand, Good Stucco Practice 1996.

P. McHenry, John Wiley and Sons, Adobe and Rammed Earth Buildings, 1984.

J. Tibbets, Southwest Soladobe School, The Earthbuilders Encyclopaedia, 1989.

The users of this Standard should ensure that their copies of the above-mentioned New Zealand Standards or of overseas Standards approved as suitable for use in New Zealand are the latest revisions or include the latest amendments. Such amendments are listed in the annual Standards New Zealand *Catalogue* which is supplemented by

FOREWORD

General

This standard and the associated NZS 4297 *Engineering design of earth buildings* and NZS 4299 *Earth buildings not requiring specific design* extend the range of construction and structural design standards to cater for the growing interest in earth building. Earth is becoming increasingly important in the context of the modern desire for construction materials which are less highly processed and have low toxicity. These standards formalize the current state-of-the-art knowledge of the design and construction using a building method that has provided satisfactory shelter to millions of people around the world over many centuries. As earth is a heavy, low-strength material, its use in construction is expected to essentially be limited to single storey walls and ground floors.

The enthusiastic support of Yvonne Rust as a prime promoter of the need for earth building standards in New Zealand is recognized and the role of the Earth Building Association of New Zealand in supporting the development of this suite of standards is acknowledged. Many other people and organizations, too numerous to name have also made valuable contributions.

Earth wall construction includes a diverse range of techniques to build either monolithic walls or ones made from individually laid bricks. The action of the complete wall in respect of strength, deformation and damage depends very much on the standard of workmanship, and, in the case of earth brick walls, the strength and durability of the individual components and their arrangements. Frequently earth buildings are constructed from local soils available near the construction site. Because of these variables, and because of the restricted availability (compared with other materials) of rigorous laboratory test results, the performance of some elements under severe deformation is less well known or predictable than with other materials. However, earth wall construction is one of the oldest building techniques in the world and earth walls have performed adequately in many situations.

These three new standards have been prepared with the intention of seeking Building Industry Authority acceptance for referencing in the NZBC Approved Documents.

It is always a challenge in writing building standards to balance the need for versatility and flexibility with the need to keep it simple and compact. The scope of these standards therefore excludes items such as vaults and domes and walls which curve for lateral stability. The fact that something is not covered by a standard does not mean it is prohibited. What it does mean is that if one is wishing to build, say a dome, some other means of proving compliance with the requirements of the Building Code will need to be found. Such proof can rely in part but not solely on these standards.

The process of earth building usually involves the following steps, not necessarily in this order:

(1) Locate suitable building site.
(2) Select a preferred earth building technique.
(3) Consider suitability of local or nearby subsoils for various construction methods.
(4) Carry out field tests of possible construction soils to check their suitability for the preferred construction method. Modify method if necessary.
(5) Carry out pre-construction testing of earth building material. Modify mix as required.
(6) Design building and obtain building consent.
(7) Carry out site work and building construction including quality control testing.
(8) Obtain Code Compliance Certificate.

The manner in which the three standards cover these steps is set out below.

Engineering design of earth buildings
NZS 4297 is primarily aimed at structural and performance aspects of step 6. Together with NZS 4298, it gives limitations to consider for steps (1), (2), (3), (4), (5) and (7). It is intended for use by structural engineers. Other publications and expert help can provide additional advice covering all these points and issues of aesthetics.

In New Zealand, the seismic provisions of NZS 4297 will govern design in most cases. Many of the structural design principles are chosen to be similar to those for masonry (reinforced or unreinforced) 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.

Limit State Design Principles have been used in the formulation of this standard to be consistent with other material design standards. Durability is important and is covered by a design method which relates required durability test results to the annual rainfall and exposure of a building site.

mode of walls at large deformation. Earthquake loads are analysed using the energy method proposed by the New Zealand National Society for Earthquake Engineering for strength assessment of unreinforced masonry earthquake risk buildings.

Materials and workmanship for earth buildings
NZS 4298 sets out requirements for the materials and workmanship requirements for the use of unfired earth in the form of adobe, pressed earth brick, rammed earth or poured earth. NZS 4298 gives significant help for steps 4, 5, 6 and 7 noted above. It applies to buildings which

are designed in accordance with NZS 4297 *Engineering design of earth buildings* and NZS 4299 *Earth buildings not requiring specific design*.

Commentary to this standard takes heed of the long history of successful earth building worldwide. A feature of this experience is the diversity of building methods.

It is necessary to demonstrate that earthen materials used (with or without admixtures) produce results meeting 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 building code requirements.

Earth buildings not requiring specific design
NZS 4299 is the earth building equivalent of NZS 3604 but with its coverage limited to foundations, floor slabs and walls. It is intended that owner-builders or supervising owners with appropriate experienced help will be able to use NZS 4299 alongside NZS 4298 to carry out steps (1) to (8).

Again balancing the need for versatility and flexibility with the need for simplicity has produced restrictions on the scope of buildings covered. More ambitious structures can be designed by a structural engineer using NZS 4297.

The inclusion of drawings of construction details which have been proved in the New Zealand setting is intended to help builders in earth to achieve durable, weatherproof and successful buildings.

REVIEW OF STANDARDS

Suggestions for improvement of this Standard will be welcomed. They should be sent to the Chief Executive, Standards New Zealand, Private Bag 2439, Wellington 6020.

NEW ZEALAND STANDARD

EARTH BUILDING MATERIALS AND WORKMANSHIP

1 GENERAL

1.1 Scope and objective

1.1.1
This Standard sets out requirements for the materials and workmanship requirements for the use of unfired earth in the form of adobe, pressed earth brick, rammed earth or poured earth. This Standard applies to buildings which are designed in accordance with NZS 4297 *Engineering design of earth buildings* and NZS 4299 *Earth buildings not requiring specific design*.

> ***C1.1.1***
> *In addition to the requirements for adobe, pressed earth bricks poured earth and rammed earth, recommendations are given in an informative Appendix on cob and* in situ *adobe. Recommendations for earth floors and for surface coatings for earth walls are also included in 2 informative Appendices.*

1.1.2
Soil/cement mixtures which contain more than 15 % by weight of cement are outside the scope of this Standard.

1.1.3
Two grades of earth wall construction are provided for in this Standard. They are:

(a) Standard grade which provides minimum properties for material for:

- (i) The construction of single and two storey earth buildings in accordance with NZS 4299 and which are subject to the limitations imposed by clause 1.2 of NZS 4299; and
- (ii) Use in buildings which are subject to specific engineering design using the design strengths defined in clause 4.4.2 of NZS 4297.

Standard grade earth wall construction provides minimum properties for earth wall construction for use in buildings which are constructed in accordance with NZS 4297 or NZS 4299. Such buildings will satisfy the requirements of the clauses of the New Zealand Building Code which are set out in NZS 4297 or NZS 4299.

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 New Zealand Building Code as set out in NZS 4297.

1.1.4
The objective of this Standard is to provide a means of compliance with the materials and workmanship requirements of structures designed in accordance with either or both of NZS 4297 and NZS 4299.

> ***C1.1.4***
> *This Standard is not intended to be referenced by the New Zealand Building Code Approved Documents but NZS 4297 and NZS 4299 are intended to be referenced.*

1.2 Interpretation

1.2.1
For the purposes of this Standard the word "shall" refers to practices that are mandatory for compliance with the Standard, while the word "should" indicates a recommended practice.

1.2.2
Clauses prefixed by "C " and printed in italic type are comments, explanations, summaries of technical background, recommended practice or suggest approaches which satisfy the intent of the Standard. Corresponding mandatory clauses are not always present. They are not to be taken as the only or complete interpretation of the corresponding clause nor should they be used for determining in any way the mandatory requirements of compliance within this Standard. The Standard can be complied with if the comment is ignored.

C1.2.2
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 first performance based suite of earth building standards. Accordingly, the unusual format of having commentary clauses which have no corresponding mandatory clause has been adopted .

1.2.3
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
Dimensions, when used to describe masonry units or types of construction, refer to nominal dimensions. Actual dimensions shall be used for the purposes of calculation.

1.2.5
The terms "normative" and "informative" have been used in this Standard to define the application of the appendix to which they apply. A "normative" appendix is an integral part of a Standard, whereas an "informative" appendix is only for information and guidance.

1.3 Definitions
For the purposes of this Standard, the following definitions shall apply:

ADOBE. An air dried brick made from a puddled earth mix cast in a mould and which contains a mixture of clay, sand and silt. Sometimes contains straw or a stabilizer. Also known as mud-brick.

ASPHALT, or ASPHALT EMULSION. See bitumen.

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

BITUMEN EMULSION. Bitumen globules of microscopic size that are surrounded by and suspended in a water medium. When used as a stabilizer it is usually of the slow breaking cationic type. Also known as asphalt.

BOND, OVERLAPPING. The bond when the units of each earth brick course overlap the units in the preceding course by between 25 % and 75 % of the length of the units.

BRICK. A discrete unit of earth masonry.

CELL. A hole through or along an earth brick unit in the plane of a wall.

CHASE. A deep, wide groove cut into a constructed wall to accommodate services.

CHARACTERISTIC STRENGTH. An estimate of the lower 5 % value determined with 75 % confidence from tests on a representative sample of full size specimens.

CINVA BRICK. A pressed earth brick meeting the dimensional and strength requirements of section 6.

CLAY. A fine grained, natural, earthy material composed primarily of hydrous aluminium silicates with grain diameters less than 0.002 mm.

COB. A method of earth construction which involves placing a puddled earth mix directly into place in walls without the use of formwork or mortar.

COLD JOINT. In rammed earth construction, the joint which occurs when construction has been interrupted long enough for some degree of drying or curing to take place before fresh material is placed.

COLUMN. An isolated, reinforced, vertical loadbearing member subjected primarily to compression having a cross-section with a length to breadth ratio between 3 and 0.33.

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 stabilized soil mass causing the mass to be cemented together by the stabilizer.

DAMP PROOF COURSE. A durable waterproof material placed between materials as a protection against moisture movement. A painted on or a sheet damp proof course is referred to as a damp proof membrane.

DIAPHRAGM. A member 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.

gravel which is unfired and is free of significant organic matter.

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). Flexural strength of the material as measured in accordance with Appendix J.

FLUE. An enclosed continuous horizontal or vertical space in an earth brick element formed by the cells of the units which make up that member.

GABLE. The triangular part of an outside wall between the planes of the roof and the lines of the eaves.

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.

IN SITU ADOBE. A method of earth construction where adobe-like brick is cast directly into place on a wall.

MODULUS OF RUPTURE. See FLEXURAL TENSILE STRENGTH.

MOISTURE CONTENT. The amount of water contained in soil material expressed as the weight of the water divided by the weight of the dry soil material in percentage terms.

MORTAR. The bedding material in which earth brick units are bedded.

MUD BRICK. See ADOBE.

PERPEND. The perpendicular joint between two bricks.

PIER. (Also known as pilaster). A member similar to a column except that it is bonded into a wall. The thickness of a pier includes the thickness of the associated wall.

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 stabilizer, is poured into moulds in place on the wall being constructed. The moulds are removed when the earth is strong enough to maintain its shape.

PRESSED EARTH BRICK (or PRESSED BRICK). An earth brick that is made in a mechanical press, either machine operated or hand operated.

RAMMED EARTH. Damp or moist soil, with or without stabilizer, that is tamped in placed between temporary moveable formwork. Also known as pisé.

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 NZS 3109, 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 diameter from 0.06 to 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.

SOIL. See earth.

SPACING. The distance at which members are spaced measured centre to centre.

STABILIZATION. The improvement of the performance of earth building material properties by the addition of materials which bind the earth particles. Stabilization may increase the resistance of earth to moisture, reduce volume changes or improve strength or durability.

STABILIZER. A material which is used for stabilization.

STABILIZED ADOBE. Adobe bricks which have a stabilizer added, typically cement or bitumen emulsion.

STABILIZED PRESSED BRICK. Pressed brick which has had a stabilizer added, usually cement.

STABILIZED RAMMED EARTH. Rammed earth which has had a stabilizer added, usually cement.

WALL THICKNESS. Minimum thickness of wall remaining after any chasing, raking or tooling of mortar joints.

1.4 Construction review

1.4.1

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

1.4.2

The extent of review to be undertaken shall be nominated in plans and/or specifications, taking into account those materials and workmanship factors which are likely to influence the ability of the finished construction to perform in the predicted manner.

1.5 Workmanship

1.5.1

All workmanship 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.

C1.5.1
The skilled nature of some of the workmanship 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.

reasonable homogeneity and evenness throughout an individual building.

1.5.2

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

C1.5.2
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.

1.6 Application

1.6.1
Rammed earth shall comply with sections 2 and 3 of this Standard.

1.6.2
Adobe shall comply with sections 2 and 4 of this Standard.

1.6.3
Pressed earth brick shall comply with sections 2 and 5 of this Standard.

1.6.4
Cinva bricks shall comply with sections 2, 5 and 6 of this Standard.

1.6.5
Poured earth shall comply with section 2 and 7 of this Standard.

1.6.6
Where grout filling of cavities for reinforcing bars is required, bricks shall be of such type and arrangement which will be conducive to the complete filling of all the grouted cavities.

2 MATERIALS & WORKMANSHIP – GENERAL

C2 General
This section acknowledges that the quality of materials and workmanship 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 which, when designed in accordance with NZS 4297 and/or NZS 4299, comply with the performance requirements of the New Zealand Building Code as appropriate. Earth buildings can fully comply with this Standard yet exhibit a wide range of surface texture and colour.

C2.1
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, colour variations etc.) should form part of a specification. The general nature of many provisions of this Standard is due to factors which include:

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

(c) At the time of writing this Standard, there are no nationally accredited building trade training modules in existence in New Zealand which 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.

2.1.1 *Soil*

2.1.1.1
Soils which are able to be used to manufacture earth building materials which satisfy the testing requirements of 2.3 and 2.4 and which satisfy the requirements of 2.1.1.2 are within the scope of this Standard.

C2.1.1.1
Soil falling within the scope of this Standard contains clay and silt together with aggregate which 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.

2.1.1.2
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 which contain water soluble salts to an extent which will impair the strength or durability of a wall;

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

(d) Some soils 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.

(e) Soils which fail the wet/dry appraisal test given in Appendix C.

2.1.2 *Other materials and proprietary products*
Other materials and proprietary products which totally replace the binding properties of clay and silt or the strength/filler properties of aggregate with other substances are outside the scope of this Standard.

2.1.3 *Reinforcement*
Reinforcement is to be protected in accordance with 2.6.7 from corrosion and from other deterioration. Reinforcement shall be positioned in accordance with the design document prepared in accordance with NZS 4297 or NZS 4299.

C2.1.3
The role of reinforcement is to provide tensile strength to a material with otherwise low tensile strength but with significant compressive strength.

C2.1.4 *Aggregate*
Aggregate or filler is composed of small pebbles, coarse and fine sand and larger silt particles. These are the "stable" component of the earth wall and normally contribute to the bulk of the mass. They are characterised by insufficient cohesion to produce minimum bonding strength for a wall.

2.1.5 *Water*

Permitted additives to naturally occurring soils to formulate earth building materials are straw, sand, Portland cement, bitumen emulsion and hydrated lime.

C2.1.6
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.

C2.1.7 *Cementitious materials*
One role of the clays and silts 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 and/or durability characteristics of earth walling may be enhanced by the use of admixtures such as lime, sand, clay, cement or straw or by the blending of various soil types.

2.1.8 *Moisture content*
During the construction of an earth wall or the making of bricks, there must 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 G. Other materials will not form earth wall material which comply with the testing requirements of 2.3 and 2.4 if moisture content is not within an appropriate range.

2.1.9 *Storage and handling of materials*
All materials including admixtures shall be stored in such a way as to avoid contamination or premature chemical reactions. Steel reinforcement shall be protected from deterioration due to corrosion.

C2.1.9
Soils to be screened or blended are best stored in their dry state.

2.1.10 *Joints*
Joints shall conform to 2.12.

2.1.11 *Curing and drying*

2.1.11.1
Adobe and pressed earth bricks shall be cured and dried before laying. Minor surface wetting after curing and drying need not delay laying and it is noted that this is required by 4.8.1 and 5.6.2. Except as required by 2.1.11.2 and 2.1.11.3, curing shall be carried out by air drying for a minimum of 28 days in an exterior environment which is protected from strong winds and rain. They shall be protected from 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.

C2.1.11.1
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 prior to construction. Continued shrinkage may take place for an extended period of up to six months.

Bricks should be laid when dry enough to pass a knife penetration test. (A pen knife is pushed into

cracks. Adobe and poured earth are particularly susceptible to this, as larger quantities of water are used than in either pressed bricks or rammed earth.

2.1.11.2
Materials incorporating Portland cement shall have a minimum of one week of damp curing before air drying is commenced in an exterior environment which is protected from direct sunlight, strong winds and rain.

2.1.11.3
Materials incorporating hydrated lime shall be damp cured for a minimum of 3 weeks before air drying is commenced in an exterior environment which is protected from direct sunlight, strong winds and rain.

2.1.11.4
Shrinkage due to curing shall be allowed for in construction details and programme.

C2.1.11
Curing is the process of chemical changes involving water together with cement, 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-resistance surface "skin" can be observed to develop on some earth materials.

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

C2.1.12
As a general rule, it is better to build all wires, pipes 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 of too large a diameter to be chased in. Chasing down a wall also leaves a scar that is difficult to eradicate in the finished wall, unless it is being plastered. Vertical chasing is less obvious if done in corners.

2.1.12.1
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.

Holes through walls made for service inserts for drainage, water, electricity or other services shall not be wider than 200 mm.

Service cables which may impose loads on walls shall be adequately anchored.

Vertical or horizontal service ducts (conduits) may only be inserted in the central third of the wall thickness and shall not exceed 10 % of the wall thickness.

Holes entering the building below damp proof course shall be sealed so as to prevent the entry of

2.1.13 *Cement grout*
Cement grout shall be in accordance with NZS 4210.

2.1.14 *Mixing of soil*

2.1.14.1
All parts of the soil mix including any admixtures shall be thoroughly broken down to an homogeneous mass of consistent composition, texture and moisture content prior to use.

2.1.14.2
Soils containing Portland cement as a setting admixture shall be used within 45 minutes after contact between the cement and either water or moist earth.

> ***C2.1.14***
> *Consistency of mix is vital for all successful earth building. Otherwise potentially good soils can produce poor walls for want of thorough mixing. Soil mixes may be left to soak if required. Soil for adobe should be soaked for 12 hours or mechanically mixed before moulding unless cement stabilized.*

2.2 Mortar

> ***C2.2***
> *Mortar is of major importance in the overall performance of earth walls where it is utilized.*

2.2.1 *Measurement of materials*

2.2.1.1
Measurement of components shall be carried out with an accuracy appropriate to achieving consistent mortar properties.

2.2.1.2
All measurements may be carried out by volume. All mix proportion measurements in this Standard are specified by volume.

> ***C2.2.1***
> *Measurements by volume, should be in buckets or boxes of known volume with the surface struck off level.*

2.2.2 *Composition and mixing*

2.2.2.1
Mortar shall be either:

(a) Soil based mortars.
Soil based mortars may be unstabilized or may be stabilized with cement, hydrated lime or bitumen. The use of other stabilizers is outside the scope of this Standard.

or

(b) Sand/cement mortars.

Sand/cement mortars shall include sand/lime/cement mixtures.

> ***C2.2.2.1***
> *If the composition of the mortar is similar to that of the brick, the mortar bond may be improved and differential weathering is avoided.*
>
> *If rubdown of the wall is desired, it is easier if the mortar joints are still soft.*

2.2.2.2
Mortar shall contain no particles larger than half the minimum joint thickness.

2.2.2.3
Cement based mortar shall not be re-constituted once it has taken its initial set.

2.2.2.4 *Cement/sand based mortars*
The sand/cement ratio shall be within the range 6:1 to 12:1 (sand : Portland cement). Hydrated lime may also be added in up to the same proportions as the cement. Lime shall be pre-soaked for 2 hours minimum. The mortar shall be mixed so as to obtain an homogeneous, lump free mixture.

C2.2.2.4
Normal bricklaying sand is generally adequate. The sand should be "fatty" (i.e. contain sufficient clay particles to ensure the mortar will be workable). Lean sands are acceptable – they are just harder to work with and may require the addition of a small amount of plasticiser.

Mechanical mixing of mortar ingredients is the preferred method.

If mortar is mixed by hand then mixing must be thorough and complete. In most cases a mechanical mixer is required to integrate the stabilizer evenly throughout the mix.

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

2.2.2.5 *Soil-based mortars*
Mortar mixed from the same soil as the bricks need not be tested except for the shrinkage test as required by 2.3 and 2.4.

For the purposes of this clause, the sieving out of particles longer than 3 mm shall not be considered as changing the composition of the soil.

Mortar made from a different soil mix to that from which the bricks are made shall be tested as required for the bricks under 2.3 and 2.4.

C2.2.2.5
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 if there is straw in the original bricks.

Mortars high in sand will need the addition of suitable clay if the mortar exhibits a "crumbly" character when dry. Alternatively such soils should be used in cement-based mortars.

The ratios of sand/clay which give a workable mixture which meets the required test results should be worked out by trial.

If soil mortar without cement stabilizer 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

Mechanical mixing of mortar materials is the preferred method. Where a "stabilizing" agent is to be added then mechanical mixing is particularly appropriate because it ensures even integration of the stabilizer throughout the soil.

Where stabilized bricks are used many practitioners recommend that the soil mortar is of the same soil composition as the bricks and has the same degree of stabilization as the bricks as far as possible consistent with other performance criteria. However, soil that is suitable for making pressed earth bricks may not make suitable mortar when wet enough for mortar workability.

2.2.3 *Properties*

2.2.3.1
This clause applies to both soil-based mortars and cement-based mortars.

2.2.3.2
Mortars shall comply with the appropriate testing requirements of 2.3 and 2.4.

2.2.3.3
Mortars shall have the minimum moisture content required for workability.

2.2.3.4
The mortar shall be mixed to a consistency which 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.

C2.2.3.4
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.

2.2.3.5
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 cracks at the brick-mortar interface, or holes in the mortar surface shall be repaired using the same mortar materials.

C2.2.3.5
The mortar should form an adequate bond with the earth bricks when completely dry. If the mortar is to be washed down during the laying process before it has completely hardened then it seems to be easier to undertake this task with mortars (both cement based and soil based) having a higher rather than a lower clay content.

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.

2.2.3.6
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 sand/cement mortars or 15 mm for soil-based mortars.

C2.2.3.6
Further desirable properties of mortar are as follows:

(a) It does not exhibit excessive cracking;

(b) It bonds adequately with the earth bricks;

(c) It needs to contain sufficient fines for good bonding but also enough sand to facilitate spreading.

2.2.4 *Workmanship*

2.2.4.1
This clause applies to both soil based mortars and cement based mortars.

2.2.4.2
Mortar beds shall be full width and flush except as provided by 2.2.4.3. 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.

> ***C2.2.4.2***
> *Where the bricks are exposed it is best if the walls are finished flush or "bagged off".*
>
> *This is best achieved 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 workmanship which applies to other bricklaying in so far 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 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 hard plastering is to be applied to the earth brick/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.*

2.2.4.3
Where mortar joints in walls are to be raked, the structural effects of the raking shall be taken into account by specific design in accordance with NZS 4297 and relevant details shall be included in the plans and specifications.

> ***C2.2.4.3***
>
> *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 nonetheless should under no circumstances 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.*

2.2.4.4
Bricks shall be moistened before laying as required by 4.8.1 and 5.6.2.

> ***C2.2.4.4***
> *Moistening the bricks reduces the rate of drying of the mortar. Excessive moisture will reduce bond and increase shrinkage.*

2.3 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 2.3.1 and 2.3.2.

> ***C2.3***
> *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 specific engineering design in accordance with the design strengths given by table 4.1 of NZS 4297.*
>
> *It is necessary to demonstrate that earthen materials used (with or without admixtures) produce results meeting at least the minimum standards 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.*

2.3.1 *Tests before commencing construction*

2.3.1.1
The tests indicated in table 2.1 shall be carried out prior to work commencing on a building. Test results which meet or exceed the requirements of the relevant test shall be obtained. Records shall be kept which permit the identification of the earth building materials used and their proportions in each test specimen. The materials tested shall be representative of materials which are to be incorporated in the building. Earth building material to be incorporated in a building shall comply with the testing requirements of this clause.

> ***C2.3.1.1***
> *Investigations of the materials likely to be used on a project should be sufficiently detailed to locate any earth building material which is likely to be used on a project and which has significant variations in properties which may significantly affect test results.*
>
> *Flexural tensile strength (modulus of rupture) is very variable with most results lying between 10 % and 20 % of compressive strength. The ratio also varies depending on whether bricks are*
>
> *adobe, has been adopted as the benchmark.*
>
> *Laboratory compression tests will give more consistent results.*

2.3.1.2
Prior to being tested, samples shall be air dried for 28 days in an exterior environment which is protected from strong winds and rain and, for the first 4 days, protected from direct sunlight. Samples shall not be oven dried. These requirements for test samples are in addition to those of 2.1.11.

2.3.1.3
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 soil changes;

(c) For adobe, every 5 000 units;

(d) For pressed earth bricks, every 2 500 units;

(e) For rammed earth or poured earth, every 200 m^3;

Table 2.1 – Tests for standard grade earth construction

Property	Appendix clause	Pressed bricks	Adobe	Rammed earth	Poured earth	Earth mortar (Note 8)	Frequency: Prior to work start	Frequency: During construction (Note 6)	Required result (Note 5)
Compression or flexural tensile strength	A5, A4, J1 or J2 (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)	$f_e > 1.3$ MPa (compression) (Note 4) $f_{et} > 0.25$ MPa (flexural tensile) (lowest of 5 results)
							1 sample of 5 or more individuals	1 sample of 5 individuals for every 2500 bricks or part thereof (Notes 2 and 3)	$f_e > 1.3$ MPa (compression) (Note 4) $f_{et} > 0.25$ MPa (flexural tensile) $f_e > 3.2$ MPa for cinva bricks (Note 4) (lowest of 5 results)
Wet/dry appraisal	C						3	Not required but see Note 2	Pass
Durability	D or E						1 spray (App. D) or 2 drip (App. E)	Not required but see Note 2	As required by NZS 4297 or NZS 4298
Shrinkage	F						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 cement ≤3.0 % for mortar without cement for poured earth see 7.8.2
On-site moisture handful drop test	G						1 for each test or batch	1 per batch	Appendix G
Whole brick drop test	H					Note 9	2	1 sample of 5 individuals for every 5000 bricks or part thereof (Notes 2 and 3)	Pass
		√			√		2	1 sample of 5 individuals for every 2500 bricks or part thereof (Notes 2 and 3)	Pass
Layering test	N	√					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 2 bricks per sample

NOTES TO TABLE 2.1

(1) One of the 4 nominated tests shall be used except as provided for in Note 3.
(2) Plus extra tests where any evidence of change of soil.
(3) If sample passes whole brick drop tests (Appendix H) during construction, compression and flexural tensile tests are not required during construction.
(4) The tabulated required results, f_{espl} (the least of the 5 individual results in the set) are for samples with height/thickness ratio of 1.0. For samples with other height/thickness ratios the required result, f_{espl}, shall be the tabulated value *0.7/ k_a where k_a, the aspect ratio factor, is determined in accordance with A4.3.
(5) Refer to B3.3 for abnormal tests results.
(6) For plants producing earth building materials from the same source or sources for a number of structures then the test frequencies of 2.3.1.3 shall apply.
(7) For rammed earth or poured earth take one sample of 5 individuals every 50 m^3 of wall.
(8) For earth mortar the same composition as the bricks only shrinkage test required, otherwise all tests shall be as detailed.
(9) This test may be used to test mortar which has been cast and cured in samples the same size as the whole bricks being laid.

2.3.2 *Quality control tests during construction*

2.3.2.1
The tests indicated in table 2.1 shall be carried out at the frequencies indicated during earth building construction.

2.3.2.2
Where the results of a test fail to meet the requirements of the test then the material represented by the sample which failed shall be removed from the building unless further tests are conducted in accordance with the provisions of 2.3.2.3.

2.3.2.3
Further tests may be conducted on 5 random samples to be taken from the structure and which are representative of the material which had previously failed the test. Results of the 5 tests shall be assessed in accordance with Appendix B and if the resultant value fails to meet the minimum requirements of the test then the material represented by the samples which failed shall be removed from the building.

2.4 Materials testing for special grade earth wall construction

2.4.1 *Tests before commencing construction*

2.4.1.1
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 2.3. Where design material strengths to be relied upon are in excess of the values in table 4.1 of NZS 4297 then those design strengths shall be determined in

Appendices A, C, D, E, F and G.

> ***C2.4.1.1***
> *The design of a building may require higher standards of strength or durability than the minimums set by this Standard. Where this is the case, more stringent testing regime, than that outlined in 2.3.1 may be required. Other tests may be called for at the discretion of the designer although such testing is outside the scope of this Standard.*

2.4.1.2
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.

C2.4.1.2
This moisture content is assumed in a cured air dried sample 28 days old.

2.4.2 *Target strength for quality control*

2.4.2.1
The target average strength values for special grade earth construction shall be:

(a) Compressive strength 1.9 f_e

(b) Flexural tensile strength 2.1 f_{et}

Where the average strength of the last 5 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.

2.4.2.2
Average strengths shall be derived from test results in accordance with Appendix B.

C2.4.2
Running average of 5 samples means that the new test value for the latest sample is added to the results of the most recent 4 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.

2.4.3 *Quality control tests during construction*
The procedures of 2.3.2 shall be followed but the test results obtained shall meet the values required to confirm the characteristic strengths determined by 2.4.1 and 2.4.2.

2.4.4 *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 2 consecutive samples whose average is less than 0.65 of the target strength.

2.5 Initial preparation

2.5.1 *General*

2.5.1.1
Rubbish and organic matter, including topsoil, shall be removed from the area to be covered by the structure.

2.5.1.2
All earth walls shall be built on completed foundations constructed in accordance with NZS 4297 or NZS 4299.

2.5.1.3
The damp proof course required by NZS 4297 or NZS 4299 as appropriate shall be in place prior to commencing construction of a wall.

C2.5.1.3
It is important that an earth wall be protected from rising ground water. Attention may need to be given to site drainage.

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

2.5.3 *Starter bars*

2.5.3.1
Where reinforcement is to be incorporated within earth walls, starter bars are to be set into concrete base work.

2.5.3.2
Reinforcement shall be fixed with the following tolerances except that cover may not be reduced below that required by 2.6.7:

(a) Across the thickness of a wall ± 20 mm

(b) Along the length of a wall, for vertical bars, or along the height of a wall for horizontal bars ± 50 mm

(c) In a column or pier ± 20 mm

2.6 Reinforcement details

2.6.1 *General*

2.6.1.1
In buildings subject to specific design, reinforcement shall be as specified by the requirements of NZS 4297. Reinforcing bars shall conform to NZS 3402. Hard drawn mild steel wire shall conform to NZS 3421.

C2.6.1.1
While this Standard covers the use of steel reinforcement and polypropylene biaxial 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 etc. 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.

required by NZS 4299.

2.6.1.3
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 specific design in accordance with NZS 4297.

2.6.1.4
The use of polypropylene biaxial geogrid is permitted for horizontal reinforcement in mortar courses.

2.6.2 *Vertical reinforcement*

2.6.2.1
Vertical bars shall be spliced to starter bars in accordance with 2.6.4.

2.6.2.2
Vertical bars shall be maintained in their correct position as work progresses.

2.6.2.3
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.

2.6.2.4
Unless required otherwise by specific design each vertical bar shall be positioned in the centre of its cell, or in the middle of the cavity in grouted-cavity construction.

2.6.3 *Horizontal reinforcement*

2.6.3.1
The maximum diameter of horizontal steel reinforcement shall be 12 mm.

2.6.3.2
The use of polypropylene biaxial geogrid with square or rectangular apertures is permitted. The quality control strength of the geogrid shall be determined in accordance with BS EN ISO 10319.

2.6.3.3
Each horizontal reinforcing element shall be positioned by tying to the vertical reinforcement, by the use of specifically designed units by steel spacers or links.

2.6.3.4
Mortar joint reinforcement shall be fully embedded in mortar and shall comply with cover requirements.

2.6.4 *Splices*

2.6.4.1
Lap splices of deformed steel reinforcement shall be permitted only in concrete components or concrete grouted flues and shall be not less than 40 diameters for grade 300 steel and 54 diameters for grade 430 steel.

2.6.4.2
Splices in reinforcement embedded in earth shall be 50 mm lap welds or mechanical connections which shall be capable of developing the breaking strength of the reinforcement in tension.

C2.6.4.2
Laps in rammed earth would not be expected in bars greater than 6 mm diameter but could be used where the mechanical bond satisfies the mechanical bond requirements of 8.3.4.4 in NZS 4297.

2.6.4.3
Laps in grouted cells shall only be permitted where the least distance between the surface of a bar and the edge of a cell is 4 d_b.

2.6.4.4
Where there is more than one bar in a vertical grouted cell the laps shall be staggered to ensure that not more than one bar is lapped at any point unless a tie enclosing all bars in each cell is used.

2.6.5 *Connecting geogrid reinforcing*

2.6.5.1
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 HDPE or galvanized steel rod through the geogrid on both sides of the reinforcing rod.

2.6.5.2
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 galvanized steel rod threaded through the geogrid on the outside edge of the reinforcing rod.

2.6.6 *Tolerances*

2.6.6.1
Earth walls shall be built to the specified dimensions within the tolerances given in table 2.2.

Table 2.2 – Tolerances in earth construction

Item	Tolerance
(a) Horizontal position of any earth building element specified or shown in plan at its base or at each storey level	±30 mm
(b) 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
(c) Deviation from vertical in total height of building (from base)	±25 mm
(d) Relative displacement between load-bearing walls in adjacent storeys intended to be in vertical alignment	±30 mm
(e) Deviation (bow) from line in plan in any length up to 10 m	Single curvature: ±30 mm
(g) Deviation from specified thickness of bed joint	±30 mm average in any 3 m length
(h) Deviation from design wall thickness	–20 mm, + 40 mm

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 2 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.

2.6.6.2 *Reinforcement placing tolerances*
Reinforcement shall be placed in the specified positions within the tolerances given in clause 2.5.3.

2.6.7 *Cover and corrosion protection*

2.6.7.1
Reinforcement of mortar, earth and grout, treated as a homogeneous material, shall have a cover of not less than:

(a) 50 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 which are ungrouted or enclosed within plastic ducts.

2.6.7.2
In grouted reinforced brick construction all reinforcing bars shall be maintained at least 25 mm from earth face-shells at all points, and this space shall be filled solid with grout.

2.6.7.3
Steel reinforcing and embedded structural hardware, except bond beam dowels, shall be hot dip galvanized or painted with zinc rich paint unless it has a covering of cement/sand grout not less than 25 mm thick.

C2.6.7.3
When hard drawn steel wire is galvanized its strength is reduced.

C2.6.7.4
In aggressive environments such as, coastal, volcanic or industrial areas, particular attention shall be given to providing a resistant dense earth and, where appropriate, the covers specified in 2.6.7.1 and 2.6.7.2 may be increased or special surface protection may be provided to give enhanced life expectancy.

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

2.8 Bracing during construction

2.8.1

2.8.1.1
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.

2.8.1.2
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;

(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.

C2.8.1
Earth walls are extremely heavy and represent considerable danger to human life if unrestrained in a situation which allows them to collapse onto people.

2.9 Cold weather construction
A longer drying time may 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 may decrease the number of courses that can be laid in a day. Work shall stop when the air temperature is less than 2 ^{o}C.

2.10 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 may be needed in hot weather. In the case of earth brick walls, clean up jointing progressively. Cement or bitumen emulsion based mortar shall not be re-constituted if it has taken its initial set prematurely due to hot weather.

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

2.12 Control joints

2.12.1
Every earth wall except for adobe bricks and mortar which does not contain cement shall have control joints at spacings which will ensure that cracking which occurs will not cause the wall to fail strength or serviceability requirements.

C2.12.1
Control joints are optional in adobe construction which does not contain cement.

2.12.2
Longitudinal shrinkage in earth building materials shall be controlled by providing vertical control joints

C2.12.2
Low wall panels beneath wide windows may be prone to shrinkage cracking if the height to length ratio exceeds 1:2.

2.12.3
Vertical shrinkage control joints shall be located in rammed earth, adobe containing cement, pressed brick and poured earth as follows:

(a) At one side of an opening up to 1200 mm wide;

➤

(b) At both sides of an opening over 1200 mm wide;

(c) At abrupt changes in wall height;

(d) At changes in wall thickness;

(e) Where earth brick work is supported by a lintel, at each end of the lintel.

C2.12.3
Vertical shrinkage control joints should also be located with consideration for:

(a) Soil stability of site;

(b) Seismic zone;

(c) Overall structural integrity of the building;

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

2.12.4
Control joints shall not be located in such a way as to interfere with the requirements for bonding or stability.

2.12.5
Control joints shall be weather proof when located in exterior walls.

C2.12.5
Light should not to be visible through a control joint. Control joints should be insect proof. Neither of these properties are required for compliance with the New Zealand Building Code but are desirable attributes of quality buildings.

2.12.6
Control joints shall be constructed so as to transfer across the joint loads perpendicular to the wall face but allow expansion and contraction of each wall panel.

C2.12.6
Examples of acceptable details are given in NZS 4299.

2.13 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.

2.14 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 workmanship standards as noted below:

(a) For reinforced concrete, NZS 3109;

(b) For reinforced masonry, NZS 4210.

2.15 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 3604.

3 REQUIREMENTS ADDITIONAL TO SECTION 2 FOR RAMMED EARTH

C3 GENERAL

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

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.

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 Test 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 as described in Appendix G.

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 Test 4.1.1.

3.2.2

Acceptable compaction shall be deemed to have been achieved when the surface "rings" 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 quite acceptably some areas may be compacted to a greater degree.

C3.2.2

Differing methods of compaction may be employed so long as the required level of compaction is achieved. Differing methods of compaction may be used within the same panel of rammed earth.

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 2.6.6.1 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 2.12.

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 stabilized rammed earth all of a mixed batch shall be placed and rammed within 1 hour of the cement first coming in contact with water or damp earth except as provided by 3.5.3.

> ***C3.5.2***
> *With cement stabilized 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 1 hour 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 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

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 2.12.3, 2.12.4 and 2.12.5 are met.

> ***C3.6***
> *Cracks may occur in rammed earth walls for a variety of reasons. These include insufficient or inadequate control joints, inadequate construction practices, or localized shrinkage. Many such cracks are of no structural consequence. Where of a more minor nature cracks may be filled or patched to meet the aesthetic requirements of the project.*

C3.7 Surface finish
The surface finish may best be described as the texture and colour of a rammed earth wall. It is a function of many variables. The surface finish may be classified according to its physical characteristics such as roughness, smoothness, pebbliness, flatness, and such like. 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 may be smooth, rough or variable. Variations may be accidental or intentional.

4 REQUIREMENTS ADDITIONAL TO SECTION 2 FOR ADOBE BRICKS

C4.1 General
Bricks and earth mortar may be laid up as structural, loadbearing walls. Variations include:

(a) The stabilization of adobe with such admixtures as cement, hydrated lime and bitumen emulsion;

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

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

C4.2 Conditions of brick manufacture
Soil for adobe bricks should be soaked for at least 12 hours before moulding unless cement stabilization is used. Note that some soils will make a serviceable brick without prior soil soaking and this can be established by trial.

Adobe bricks can be moulded in one of two ways:

(a) By placing mud into a mould which 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.

Both methods depend on the air drying rather than sun baking. Excessive exposure to direct sun can accelerate surface drying and cause cracking.

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 1 week to several months, usually at least 4 weeks.

4.3 Cored units
Cores for vertical reinforcement or services shall be a maximum of 110 mm diameter or a maximum of

C4.3
The bricks may be moulded with holes to provide passage for services or reinforcement.

4.4 Straw
Straw, where used, is to be cut into lengths not exceeding half the finished wall thickness and added to the mix evenly.

C4.4
Straw is 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.

C4.5 Solid units

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

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

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

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

(d) Excessive shrinkage cracking may occur with some soils in anything but the smaller size bricks. Sand may be added to a mix to help reduce shrinkage.

(e) Straw may be added to control drying by allowing the interior of the brick to dry at a similar rate to the exterior thus reducing effects that can cause cracking.

C4.6 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 thermal 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.

4.7 Bonding

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.

C4.7

English, Flemish, garden wall and stretcher bond patterns are acceptable. These patterns are explained in NZMP 4212.

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.

4.8 Mortar joints

4.8.1 *Soaking*

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

C4.8.1

Wetting improves bond and reduces mortar shrinkage.

4.8.2 *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.

C4.8.2
Because of the method of manufacture, adobe bricks can vary as much as 10 - 15 mm in thickness. As such, mortar courses can be in the order of 15 - 50 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.

4.8.3 Shrinkage

4.8.3.1
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 tie level shall first be allowed to settle.

4.8.3.2
Fittings, frames and vertical reinforcement embedded in the wall shall be detailed to allow for shrinkage to ensure that the shrinkage can occur unrestrained.

4.8.3.3
Perpends shall be of sufficient thickness to maintain the bond between bricks within a course.

4.8.3.4
All mortar joints and courses shall be full flush, with no voids.

C4.8.3
Care should also be taken when brickwork runs across a change in floor level.

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

4.9 Control joints
Control joints shall be provided as required by 2.12.

5 REQUIREMENTS ADDITIONAL TO SECTION 2 FOR PRESSED BRICKS

5.1 General
Testing in accordance with Appendix C of soil from a particular site shall verify that the soil mixture to be used, with or without bitumen, cement, lime or cement and lime as a stabilizer, produces bricks which

cured, as building bricks. Careful soil selection is therefore necessary. It is common practice that cement is used as a stabilizer in pressed bricks.

Pressed earth bricks made from material that is not thoroughly mixed may result in unevenly bonded planes that can lead to failure. See clause 2.1.14 and Appendix N.

Service records 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 lime stabilized bricks shall be damp cured in accordance with 2.1.11.2 or 2.1.11.3 as appropriate.

C5.2
Equipment for compressing damp soil into bricks falls into 2 main categories:

(a) Manually operated devices which use a long lever arm to activate a ram within a compression chamber containing soil.

(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. These shall be not greater than 33 % of brick width and shall be a maximum at 110 mm diameter or a maximum of 95 mm square. Holes shall be filled with grout or mortar as installation proceeds.

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 may not be generally available.

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

(a) Reduces potential breakage of bricks if they are required to be transported;

(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.

C5.4 Solid units

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

(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.

5.5 Grout spaces

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

5.6 Laying

5.6.1

Bricks are to be laid in an overlapping bond pattern.

> ***C5.6.1***
> *The constraints of the manufacturing process which 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 figures 5.2(c) and (d) may be used.*
>
> *Refer to C4.7 for acceptable bond types.*

5.6.2

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

> ***C5.6.2***
> *Compression planes are generally formed perpendicular to the direction of the ram in the brick press. In walls, the compression plane is normally horizontal.*

5.6.3

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

> ***C5.6.3***
> *Wetting of bricks greatly enhances mortar bond strength and reduces excessive shrinkage and therefore cracking of mortar.*

5.6.4

Where one wall meets another in a "tee" intersection then every second brick should be let at least 100 mm into the abutting wall (see figures 5.2(a) and (c)). In the case of square bricks refer to figure 5.2.

5.6.5

Reinforcing (steel bar or geogrid) shall be used in every fourth course with a maximum vertical spacing

5.7 Mortar joints

5.7.1

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 tie level shall first be allowed to settle. Provision shall be made for differing settlement where brickwork runs across a change in floor level.

5.7.2

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

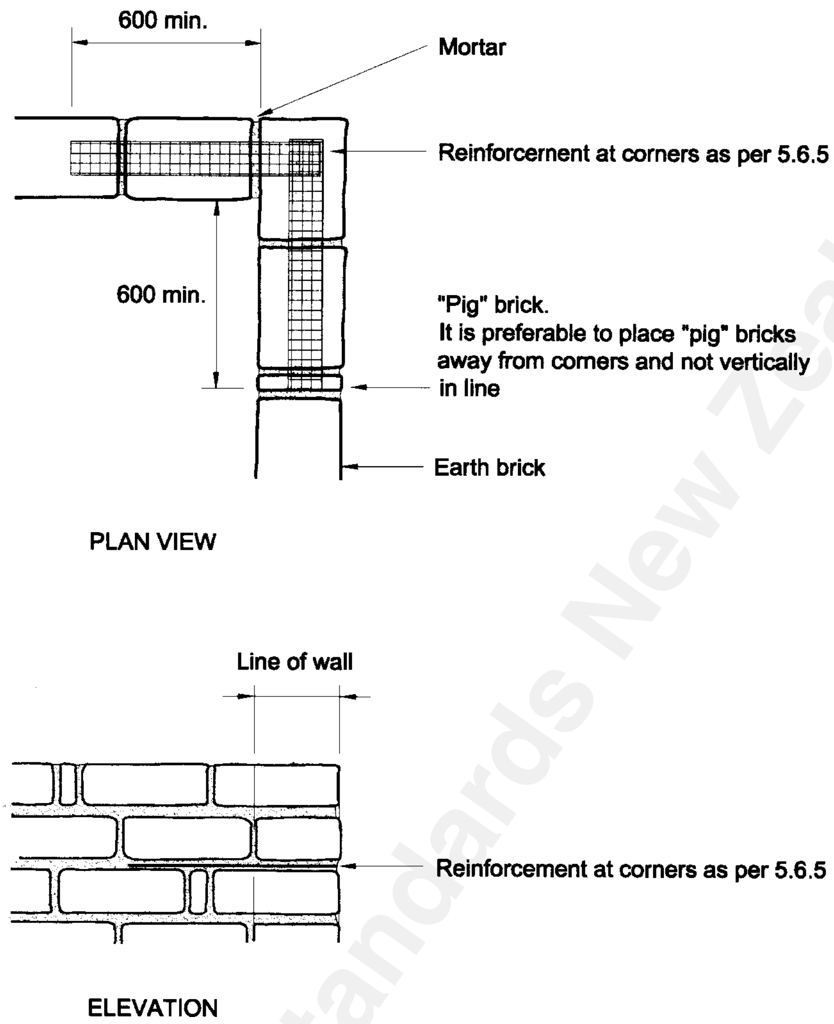


Figure 5.1 – Pressed brick bond at corner

5.7.3
Mortar courses shall be full with no internal voids.

5.7.4
Mortar courses may be raked only in accordance with 2.2.4.2 and 2.2.4.3.

5.7.5
Mortar shall be sufficiently thick to ensure that bricks do not bed in direct contact with one another.

C5.7
If soil type and moisture content are consistent, pressed bricks are usually of a consistent dimension in at least 2 directions. Variations in the dimension parallel to the direction of the ram movement can occur. This depends on the sophistication of the measuring of both the soil 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 subside more during curing.

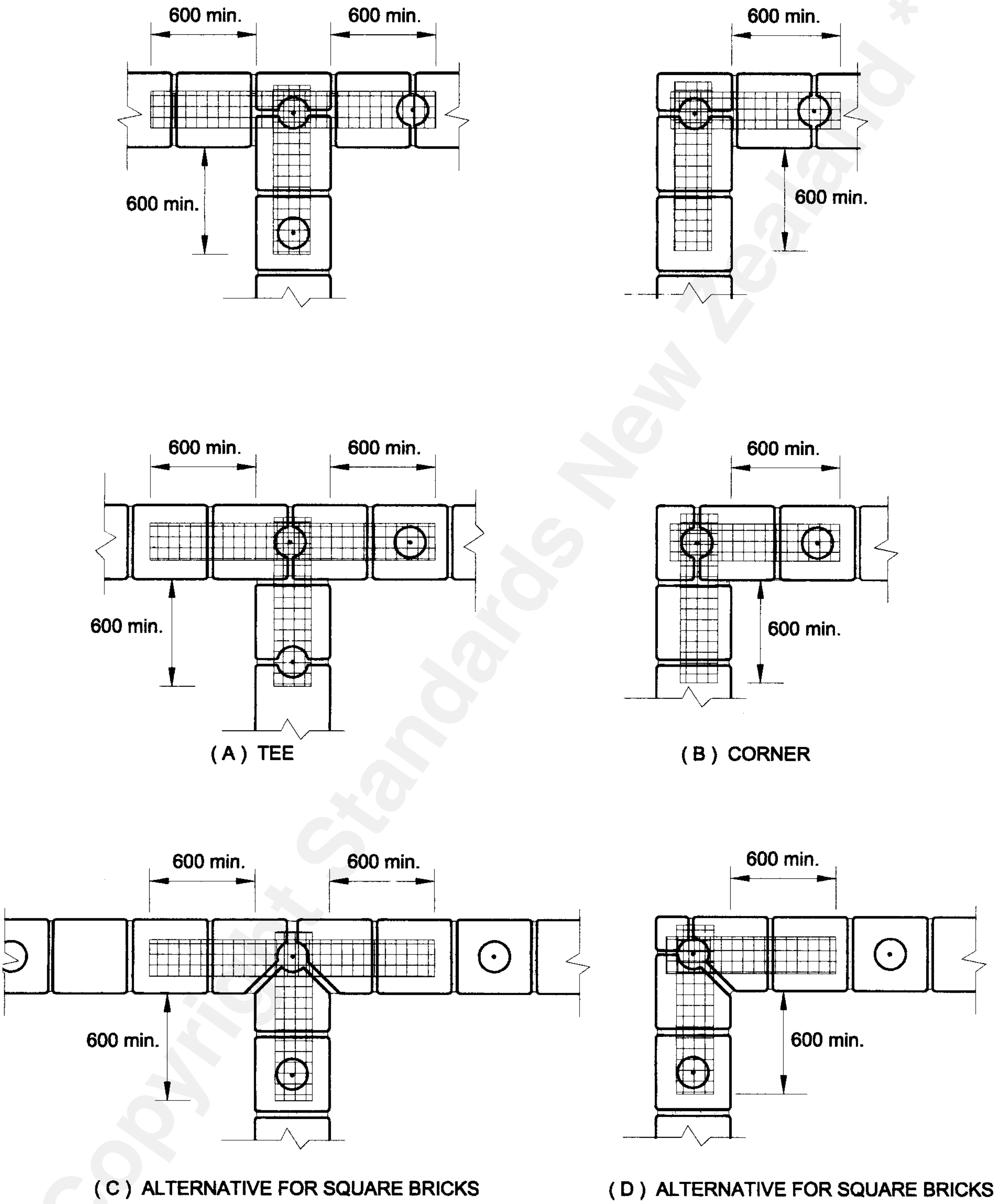


Figure 5.2 – Pressed brick bond at "tee" intersections and corners

6 REQUIREMENTS ADDITIONAL TO SECTION 5, FOR CINVA BRICKS

6.1 General

6.1.1
Section 5 shall apply with the following additions and variations.

6.1.2
Particle size shall be no greater than 7 mm.

6.1.3
Portland cement shall be used as a stabilizer.

6.1.4
The compression strength shall be 2.0 MPa for bricks tested on end (the 300 mm dimension vertical) or 3.6 MPa when tested on the flat (the 300 mm x 140 mm face horizontal).

6.1.5
Only mortar of sand and Portland cement as described in 2.2 shall be used to lay the bricks.

6.2 Holes
All holes in a course shall be filled with a sand-cement mortar as each brick course is laid. The mortar shall be of one part cement to 6 parts sand by volume together with up to one part lime putty which may be used for improved workability.

6.3 Dimensions
Cinva bricks shall have the dimensions shown in figure 6.1.

C6.3

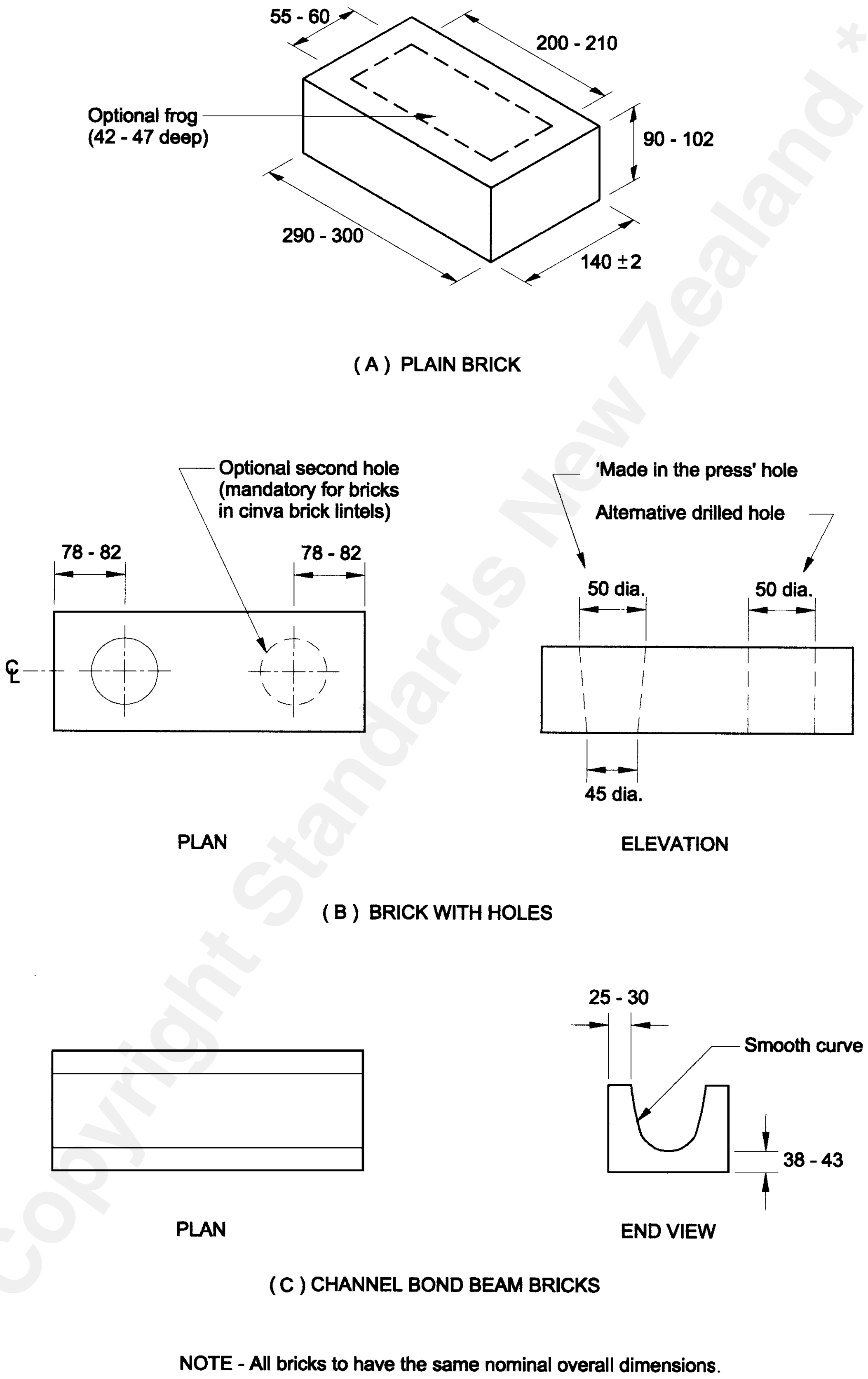


Figure 6.1 – Cinva brick dimensions

7 REQUIREMENTS ADDITIONAL TO SECTION 2 FOR POURED EARTH

C7.1 General

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 bricks 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 bricks in the preceding lower course are filled. A number of proprietary moulding systems are available.

While poured earth may be practised without stabilization, it is more usual in New Zealand to include 5 – 10 % Portland cement in the mix to reduce shrinkage and to enhance the strength and durability of the walls. Soils used for poured earth generally have a lower clay content than might be used for adobe because while adobes can shrink prior to be being laid in the wall, poured earth does all its shrinkage in the wall and excessive shrinkage can cause problems. New work is also required to bond to previous layers.

7.2 Material and mixes

7.2.1 *Soil*

Soils for poured earth shall be soaked for at least 12 hours before moulding unless cement stabilization is used in which case the mix may be worked up from dry.

7.2.2

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

C7.2.2

Test panels or previous experience with the proposed soil mix which demonstrates the suitability of particles larger than 25 mm may 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.

7.2.3 *Moisture content*

The moisture content of an earth mix for poured earth is critical for shrinkage reasons, and shall therefore be limited to the minimum amount necessary for workability.

Typically with cement stabilized poured earth, around 50 % of the shrinkage takes place within the first 48 hours and 90 % within 2 weeks.

7.2.4 *Fresh mix containing cement*

For poured earth containing cement, all of a mix shall be placed and moulded within 1 hour of the cement first coming in contact with water or damp earth except as provided for in 7.2.5.

7.2.5 *Stale mix containing cement*

Stale mix, being that which is older than 1 hour 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 of 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.

C7.2.5
The use of mixes comprising part stale mix may 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.

7.3 Method of construction

7.3.1
Poured earth is placed into the moulds ensuring that there are no voids. Vibrators must be used with extreme care to ensure that there is no segregation of particles within the mix.

7.3.2
The top surface is screeded flat while the mould is still in place and then roughened to 5 mm amplitude before the material is fully hardened to enhance the bond with subsequent courses.

7.3.3
The surface of previous work is to be thoroughly wetted immediately prior to placing of subsequent work.

C7.3.3
Wetting prevents premature drying at the joint and improves bond strength.

7.4 Curing and drying

7.4.1
All work shall be dried evenly and with limits on the rate of drying to prevent premature surface drying and subsequent shrinkage cracking. This shall be achieved by sheltering the wall with fabric or plastic film from the effects of direct sun exposure and from strong winds.

C7.4.1
Excessive exposure to direct sun or strong wind can cause uneven drying and consequential cracking.

7.4.2
All work containing Portland cement shall be moist cured by being covered with fabric kept damp for a minimum of 7 days before being allowed to dry.

7.4.3

7.5 Preferred sizes
There are no preferred nominal sizes for poured earth.

C7.5
In practice it has been found that limiting the amount poured in one unit to less that 0.2 m^3 is a sensible limit for good performance.

7.6 Shrinkage

7.6.1
Vertical settlement of poured earth caused by shrinkage shall be considered when detailing around services, or adjoining structure, or reinforcing steel (see 2.1.12).

C7.6.1

Walls made by this method may 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.

7.7 Control joints

7.7.1

Vertical control joints to control horizontal shrinkage shall be provided as required by 2.12, with a maximum distance between control joints of 3.6 m. Additionally control joints are to be located both sides under a window opening.

7.7.2

All control joints shall be detailed to resist weather ingress.

7.8 Testing

7.8.1

Samples for compression testing or flexural tensile strength testing shall be cast into moulds as for adobe. These shall be tested as required by 2.3 or 2.4.

7.8.2 *Shrinkage*

Maximum shrinkage allowed is 0.2 % over a 600 mm sample or 0.05 % over a 3.6 m section, with interpolation for lengths in between.

APPENDIX A
DETERMINATION OF STRENGTH OF UNIT SPECIMENS
(Normative)

A1 SCOPE

A1.1 General
This Appendix sets out the method for constructing and testing specimens for determining:

(a) The compressive strength of earth brick piers (see A2); and

(b) The flexural strength of earth brick perpendicular to the bed joints by means of the bond wrench test method (see A3);

(c) Compression tests for individual wall units, rammed earth, mortar and grout (see A4);

(d) Compression tests for cinva bricks (see A5).

A2 EARTH BRICK PIERS

A2.1
Piers shall be made up of an even number of bricks and shall have an aspect ratio of between 3 and 5.

A2.2
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.

A2.3
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 category II or III as defined in NZS 4203.

A3 FLEXURAL BOND BY BOND WRENCH TEST

A3.1
Testing shall be as per Appendix 2B of NZS 4210.

A4 COMPRESSION TESTS OF INDIVIDUAL WALL UNITS, MORTAR OR GROUT

A4.1

in the wall.

A4.2
Samples shall be loaded in the same direction as will occur in the wall and shall have a height to least width ratio (aspect ratio) of between 0.4 and 5.0.

A4.3
The failure stress of each specimen shall be multiplied by the aspect ratio correct factor (k_a) given in table A1 to yield the unconfined compressive strength of the specimen. Linear interpolation is to be used.

A4.4
The characteristic unconfined compressive strength (f'_{uc}) of the sample shall be determined in accordance with Appendix B.

CA4
For strength test samples for the liquid techniques (adobe, in situ adobe, 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.

A5 RAMMED EARTH

A5.1
Rammed earth samples shall be prepared the same way whether the earth is stabilized or unstabilized.

A5.2
Samples may be prepared in the field or in the laboratory.

A5.3
Sample height to width ratio of 2 to 1 is a commonly accepted industry standard. To correct for sample height effects reference should be made to table A1.

A5.4
Samples shall be compacted as per 3.2.2.

A5.5
Mortar and grout shall be tested as cylinders of 2 to 1 height-to-width ratio.

A6 CINVA BRICKS

A6.1
Cinva bricks shall be compression tested either vertically by standing on end (i.e. the 300 mm dimension being vertical), or on the flat with their 300 mm x 150 mm face being horizontal.

A6.2
Bricks with a frog shall not be tested vertically.

A6.3
For horizontal testing the brick shall be a solid unit without holes or recesses and with any frogs filled in accordance with A6.4.

A6.4
Bricks with a frog may be tested after the frog has been filled with 4:1 sand/Portland cement mortar which has been cured for at least 14 days. The mortar shall be placed in the frog 14 days after brick manufacture.

A6.5
The area used for calculating the compressive strength for testing as per A6.4 shall be the gross horizontal area of the whole brick.

Table A1 – Aspect ratio factor (k_a)

Height to thickness ratio	0.4	1.0	2.0	5.0 or more
Aspect ratio factor (k_a)	0.50	0.70	0.80	1.00

NOTE –
(1) Table A1 is used to provide the aspect ratio factor for adjusting compression test results for earth bricks.
(2) The thickness used for evaluating the height-to-thickness ratio is the overall width of the unit.
(3) Linear interpolation shall be used.

A7 AGE OF TEST

Samples shall be a minimum of 28 days old when tested.

A8 TEST REPORTING

Test reports shall include:

(a) Age;

(b) Dimensions;

(c) Mass;

APPENDIX B
ASSESSMENT OF DESIGN STRENGTH VALUE FROM TEST RESULTS

(Normative)

B1 SCOPE

B1.1 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.

B1.2 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_{spl}	the least of the individual results in the set
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_{spe}	the average value of all test results for the set under consideration excluding the suspected abnormal result
f_{spa}	suspected abnormal test result
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
$X_1, X_2, ... X_i ... X_n$	Group of n test results (Applicable to methods of B3.1 and B3.2)
x_1, x_2, x_3, x_4	Lowest, second lowest, third lowest, fourth lowest test results respectively. (Applicable to methods of B4.1 and B4.2)
δ	the coefficient of variation for the set under consideration excluding the suspected abnormal result
ε	dimensionless factor used in formulae of B4.2.

B2 TEST SPECIMENS

B2.1 Obtaining samples for testing prior to construction

B2.1.1
If the production process has been finalised and early production is underway, testing shall be carried out in accordance with this clause.

B2.1.2
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 5 times the number of specimens for the required sample.

B2.2 Construction of test specimens prior to production

B2.2.1
Where production plant is not in place test specimens may be constructed to the requirements of this clause.

B2.2.2
Test specimens shall be made from materials that are representative of the earth material or earth bricks whose characteristic strength is to be determined, and, as far as practicable, using similar techniques and standards of workmanship and under similar conditions to those that are (or will be) applicable for earth walls constructed of that material.

B2.3 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 5 specimens are accumulated, at the completion of any stage of the project, or when any change in earth materials is apparent.

B3 TEST RESULTS

B3.1 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:

$$X_a = \frac{X_1 + X_2 + \ldots X_i + \ldots X_n}{n}$$

B3.2 Standard deviation
The unbiased standard deviation X_s (sample standard deviation as distinct from population standard

consideration after elimination of abnormal results in accordance with B3.3, shall be calculated as:

$$X_s = \sqrt{\frac{\sum X_i^2 - nX_a^2}{n-1}}$$

B3.3 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 $f_{spe} \pm 3\,\delta f_{spe}$

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

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

B4 EVALUATION OF CHARACTERISTIC STRENGTH

B4.1 Method for 5 results

Where the results of testing only 5 specimens are available the following may be used to evaluate the characteristic strength:

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

where x_1 is the lowest result.

> ***CB4.1***
> *This is equivalent to n = 5 and $k_k = 0.925$ ($\delta = 0.05$), $k_k = 0.775$ ($\delta = 0.15$), $k_k = 0.625$ ($\delta = 0.25$) which is in good agreement with AS 3700 Appendix B and errs on the conservative side if $\delta > 0.15$.*

B4.2 Characteristic value for sample size ten or greater, where 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 $n = 10 - 19$

$f' = x_3^{1-\varepsilon}.(x_2.x_1)^{\varepsilon/2}$ 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 $n = 20 - 29$

$f' = x_4^{1-\varepsilon}.(x_3.x_2.x_1)^{\varepsilon/3}$ 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

CB4.2

Example

For a series of 10 test results for which the lowest 3 values are 1.45, 1.75 and 1.84. For n = 10 the ε value is 3.31

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

Note that x_1, x_2, x_3, x_4 *are the lowest, second lowest, third lowest, fourth lowest test results respectively (see B1.2).*

This characteristic strength approach is based on the Ofverbeck Power Method Ofverbeck, P. (1980) Small Sample Control and Structural Safety. Rep.TVBK-3009, Dept. of Struct. Engrg., 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.

B4.3 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 AS 3700, Appendix B shall be used.

B5 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.

APPENDIX C
WET/DRY APPRAISAL TEST

(Normative)

C1 GENERAL

This cyclic wet/dry test is to eliminate reactive soils and soils or soil/stabilizer mixes with unacceptable properties.

CC1
This test is to eliminate unsuitable earth building materials which 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.

C2 EQUIPMENT

C2.1

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;

(b) Three 20 cent coins.

C3 PROCEDURE

C3.1

Two identical sample bricks are selected. One, the reference brick, is set aside. Alternatively, 2 opposite faces of the same brick may be used – one for testing, one for reference.

C3.2

Soak one face of the sample supported approximately 2 mm above the base of the dish by three 20 cent coins placed under it in water of 10 mm initial depth for the following periods:

4 minutes for materials which are required to have an erodibility index of 1
2 minutes for materials which are required to have an erodibility index of 2
1 minute for materials which are required to have an erodibility index of 3
0.5 minutes for materials which are required to have an erodibility index of 4

The face to be soaked shall be a face which is intended to be a vertical face when the brick is incorporated into a wall.

CC3.2
The soaked face will normally be the longest side face of a brick.

C3.3

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.

C3.4
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 5 locations;

(e) Local or general fretting, that is loss of layers of soil 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 which come from within 50 mm of the edges of the brick shall not be included;

(h) Efflorescence, that is powdery crystals, on the brick surface. It is usually white.

C3.5
Repeat steps C3.2 to C3.4 for a total of 6 cycles. The same face shall be soaked in each cycle.

C3.6
On the sixth cycle the sample is to be dried for 2 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.

C4 ACCEPTANCE CRITERIA
The soil or soil mix represented by the sample is acceptable if, during or at the completion of the procedure detailed in C3, there has been no appearance of any of the conditions noted in C3.4.

APPENDIX D
EROSION TEST (PRESSURE SPRAY METHOD)
(Normative)

D1 GENERAL
The test consists of spraying the face of a prepared sample of the soil for a period of 1 hour or until the specimen is penetrated.

CD1
The test is an empirical one developed by the former National Building Technology Centre now CSIRO (Commonwealth Scientific and Industrial Research Organisation – Australia).

D2 PROCEDURE

D2.1
The components of the equipment are shown in figure D1.

D2.2
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 1 hour or until the specimen is eroded through. The test is interrupted at 15-minute intervals and the depth of erosion recorded.

D3 RESULTS
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 one 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 D1 below.

Table D1 – Erodibility indices from pressure spray erosion test

Property	Criteria	Erodibility index
Depth of erosion D (mm/hr)	$0 \leq D < 20$ $20 \leq D < 50$ $50 \leq D < 90$ $90 \leq D < 120$ $D \leq 120$	1 2 3 4 5 (Fail)
tests) if sample thicker than 120 mm		

D4 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.

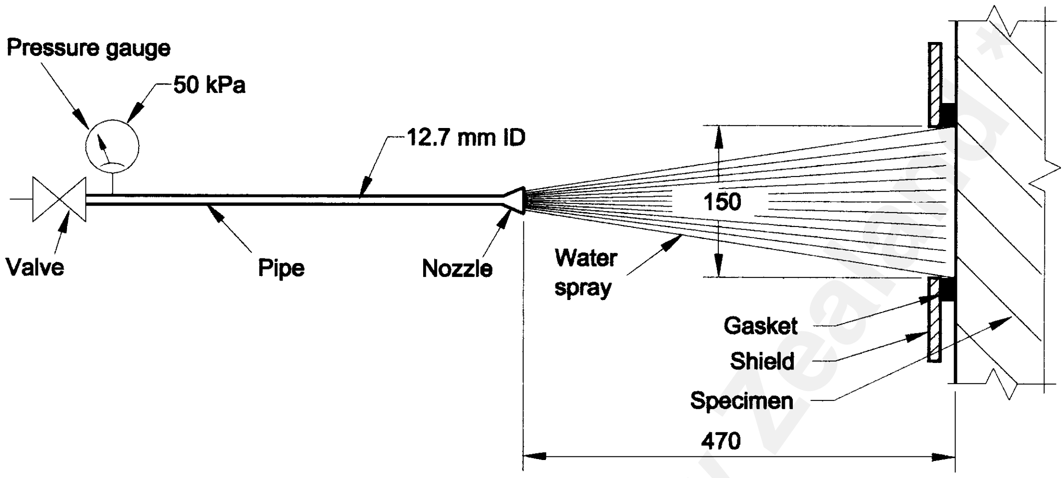


Figure D1 – Pressure spray test general arrangement

D5 CYCLIC WET/DRY APPRAISAL TEST

The cyclic wet and dry appraisal test as specified in Appendix C is required to eliminate reactive and dispersive soils.

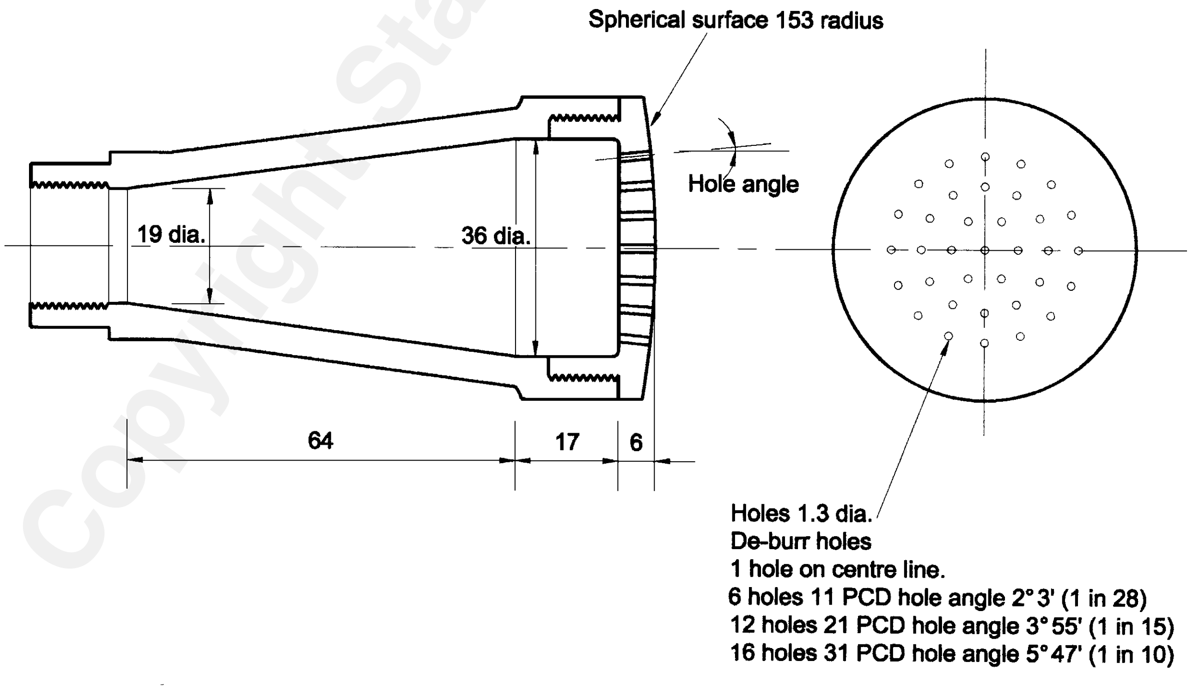


Figure D2 – Pressure spray test nozzle

APPENDIX E
EROSION TEST
(Geelong method)
(Normative)

E1 GENERAL

E1.1
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.

E1.2
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.

E1.3
Samples may be cut from existing walls of any dimension and tested with the drip onto an uncut wall face.

E1.4
The specimen shall be cured a minimum of 28 days before testing.

E1.5
This test must be carried out in a location sheltered from wind and direct sun.

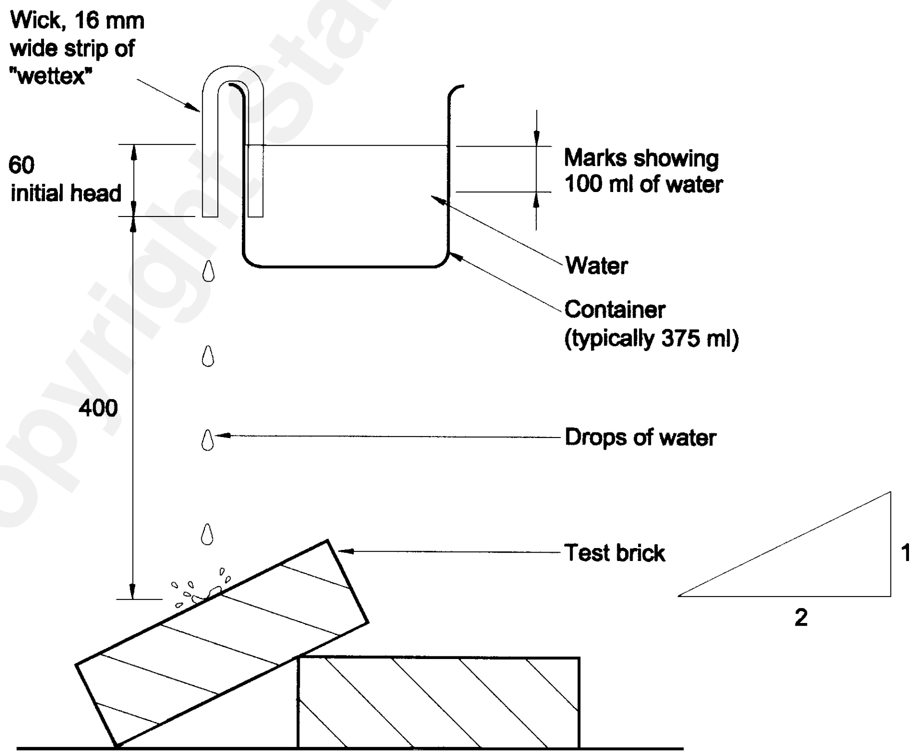


Figure E1 – Geelong method erosion test details

E2 SAMPLE BRICKS

For adobe or pressed bricks, randomly selected bricks shall be used.

E3 MEASUREMENT OF PIT DEPTH

E3.1

The pit depth is to be measured with a cylindrical probe with an end diameter of 3.15 mm.

The method is as follows:

E3.2

Allow 100 ml of water to drop 400 mm on to sloped face of test brick.

E3.3

Time taken for 100 ml to drip from container to be 20 minutes minimum to 60 minutes maximum.

> ***CE3***
> *The pit depth probe may be made from a 3.15 mm diameter ungalvanized nail filed to a square end.*

E4 CYCLIC WET/DRY APPRAISAL TEST

The cyclic wet/dry appraisal test as specified in Appendix C is required to eliminate reactive and dispersive soils.

E5 SURFACE COATINGS

The sample shall be tested without any surface coating. (See clauses L5.2, L5.3, L5.4 and L6).

E6 MOISTURE PENETRATION

E6.1

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.

E6.2

Dry the sample after testing and check for the conditions noted in Appendix C3.4. The appearance of these conditions is grounds for rejection of the material.

E7 Results

The erodibility index shall be determined by reference to table E1 below. An erodibility index of 1 shall be determined only by use of the pressure spray erosion test given in Appendix D.

	$5 \le D < 10$ $10 \le D < 15$ $D \ge 15$	3 4 5 (fail)
Depth of penetration (break sample immediately after completion of above tests) if sample thicker than 120 mm	< 120 mm ≥ 120 mm (measured from face of brick)	Pass Fail

> ***CE8 Acknowledgement***
> *This test was developed by Peter Yttrup and students at Deakin University, Geelong, Victoria, Australia.*

APPENDIX F
SHRINKAGE TEST
(Normative)

F1 THE APPARATUS

F1.1
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 x 50 mm wide x 50 mm high. Wooden boxes shall be painted or oiled to prevent moisture take up from the sample.

F1.2
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.

F1.3
The sides and bottom of the cavity shall be lined with 2 layers of newsprint to stop the material sticking to the apparatus.

CF1
Single boxes may be made or multiple boxes made side by side.

F2 PROCEDURE

F2.1
Take a sample of a proposed mix that has been prepared in the same manner as that to be used for construction.

F2.2
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.

F2.3
Ram it firmly into the shrinkage box using a suitable hand or mechanical rammer. Cure it moist for 7 days by covering the sample with plastic, then air dry out of the direct sun for a further 21 days.

F2.4
For testing a sample of poured earth, or mortar, 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 as for rammed earth samples above.

F2.5
For samples containing lime, moist cure as above for 21 days before air drying for 7 days. Ensure the sample is dry before taking measurements.

F2.6
The smoother the surface of the sample the easier it is to see cracks and assess shrinkage.

F3 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.

$$\text{Shrinkage} = \frac{\text{measured shrinkage (mm)}}{600 \text{ mm}} \times 100$$

APPENDIX G
RAMMED EARTH MIX MOISTURE CONTENT DROP TEST
(Normative)

G1 METHOD
A handful of the mixture as mixed ready to be placed between the shutters (i.e. with all components such as soil, water, 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.

CG1

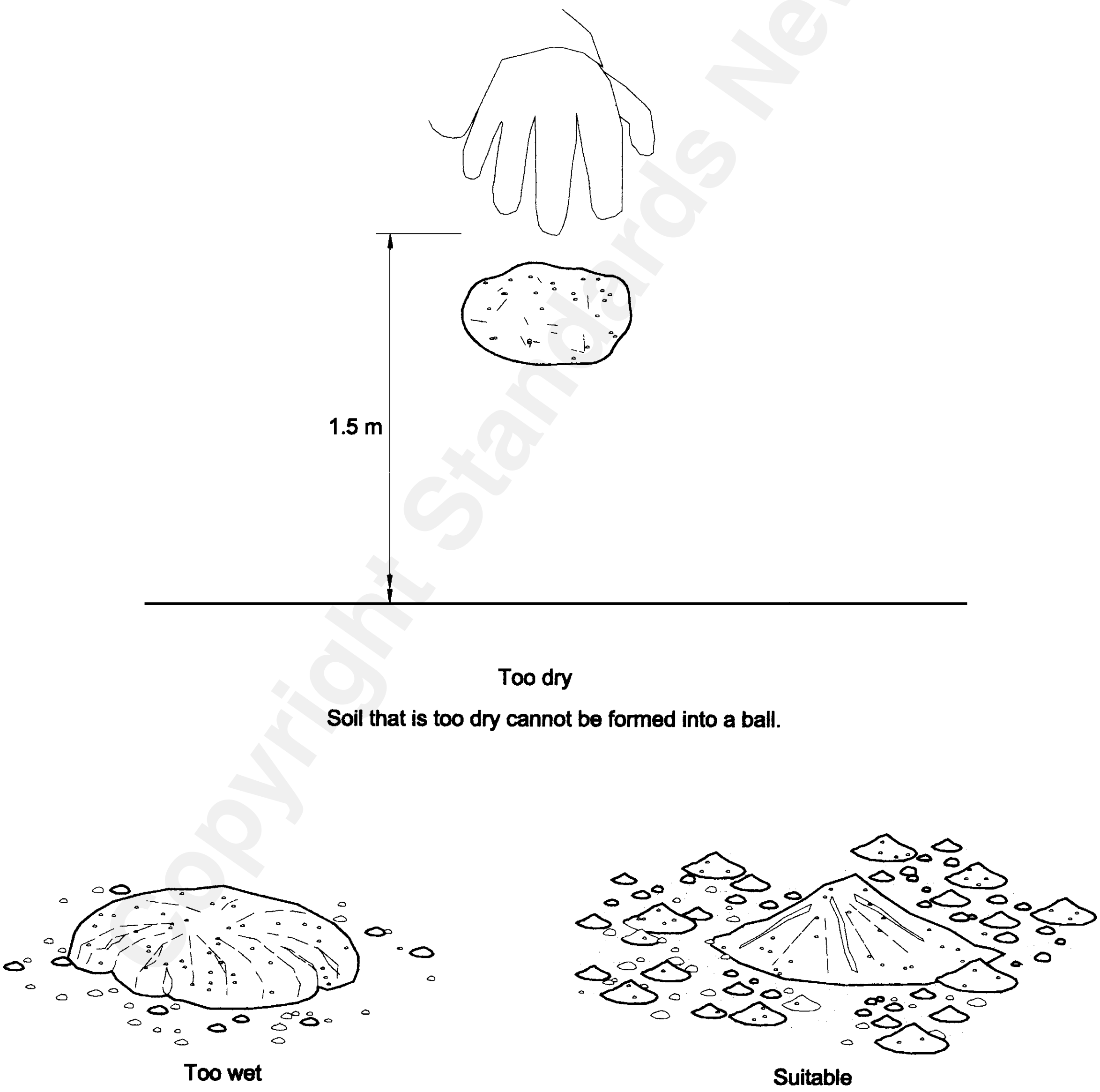


Figure G1 – Moisture content for rammed earth

G2 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 2 or 3 deformed small pieces, or stays as one deformed soggy piece, then the moisture content is too high.

CG2
A hard surface can be timber planking, concrete, or steel sheet.

APPENDIX H
EARTH BRICK DROP TEST
(Normative)

H1 GENERAL

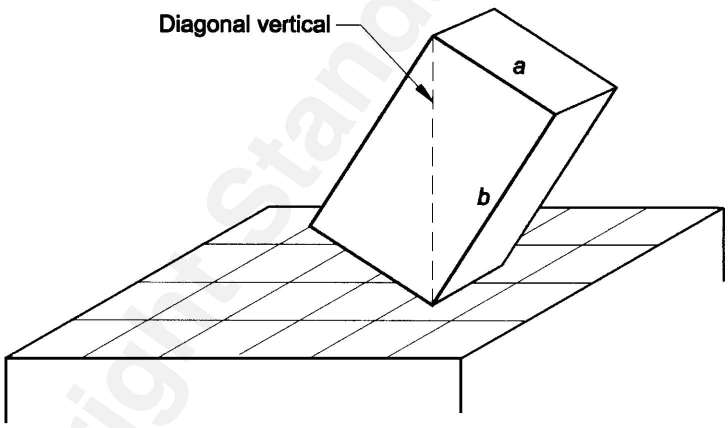
H1.1
A cured earth brick that is not less than 28 days old shall be tested in the following manner:

If a brick is longer than 2.0 times its width it shall be sawn or broken to obtain a test specimen which has a length between 1.0 and 2.0 times its width.

H1.2
It shall be held as shown in figure H1 below and dropped with its lowest point 900 mm above the point of impact on to a hard earth or harder, solidly supported surface.

CH1
This test is an adequate field test for any adobe or pressed brick, whether stabilized or unstabilized.

H2 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.



$a \leqslant b \leqslant 2a$

NOTE -
If $b>2a$, cut brick in half before testing.

Figure H1 – Orientation of earth brick prior to dropping

APPENDIX J
FLEXURAL TENSILE STRENGTH TEST
(Normative)

J1 STACKED BRICKS METHOD

CJ1
A simple field test procedure is shown below.

J1.1 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 J1 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 J2 is to be used. The length between supports of the brick being tested shall be more than twice its depth.

J1.2 Procedure

J1.2.1
The weight, *W*, of the bricks is determined by taking the average of the weights of 10 bricks which 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 which varies by more than 5 % from the average shall be discounted and the weight of another brick substituted until this criteria is met.

J1.2.2
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.

J1.2.3
The test load is applied by stacking bricks one at a time until the failure in bending is reached.

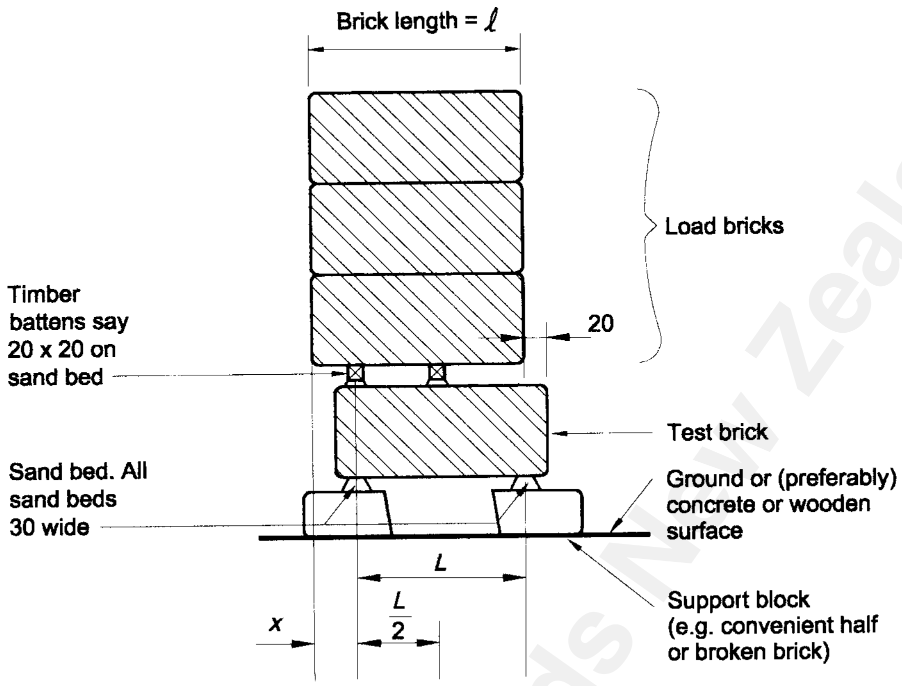


Figure J1 – Stacked bricks rupture test

J1.3 Results

The flexural tensile strength (modulus of rupture), f_{et} , is calculated from the formula:

$$f_{et} = \frac{0.015nWL}{bd^2} \times \frac{1-2x}{L} \quad \text{kPa} \qquad \text{(Eq. J1)}$$

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)
1	=	length of load bricks (m)

The result shall be recorded to the nearest 10 kPa.

CJ1.3

The formula is derived assuming that 100 kg weighs 1 kilo Newton. The factor $\frac{1-2x}{L}$ *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 J2.*

In this test $f_{et} = \frac{3}{2} \times \frac{nW(1-2x)}{bd^2}$ *kPa if W is in kN*

$f_{et} = \frac{3}{200} \times \frac{nW(1-2x)}{bd^2}$ *kPa if W is in kg*

J2 LEVER METHOD

J2.1 Equipment

J2.1.1
The apparatus of figure J2 shall be used.

J2.1.2
The length between supports of the brick being tested shall be more than twice its depth.

J2.2 Procedure

J2.2.1
The dimensions b, d, L_1, L_2 and L shall be measured to an accuracy of 1.0 mm.

J2.2.2
Load shall be added gradually until the brick fails.

J2.2.3
The beam weight, G, and the load at failure, Q, shall be determined to an accuracy of 0.2 kg.

J2.3 Results

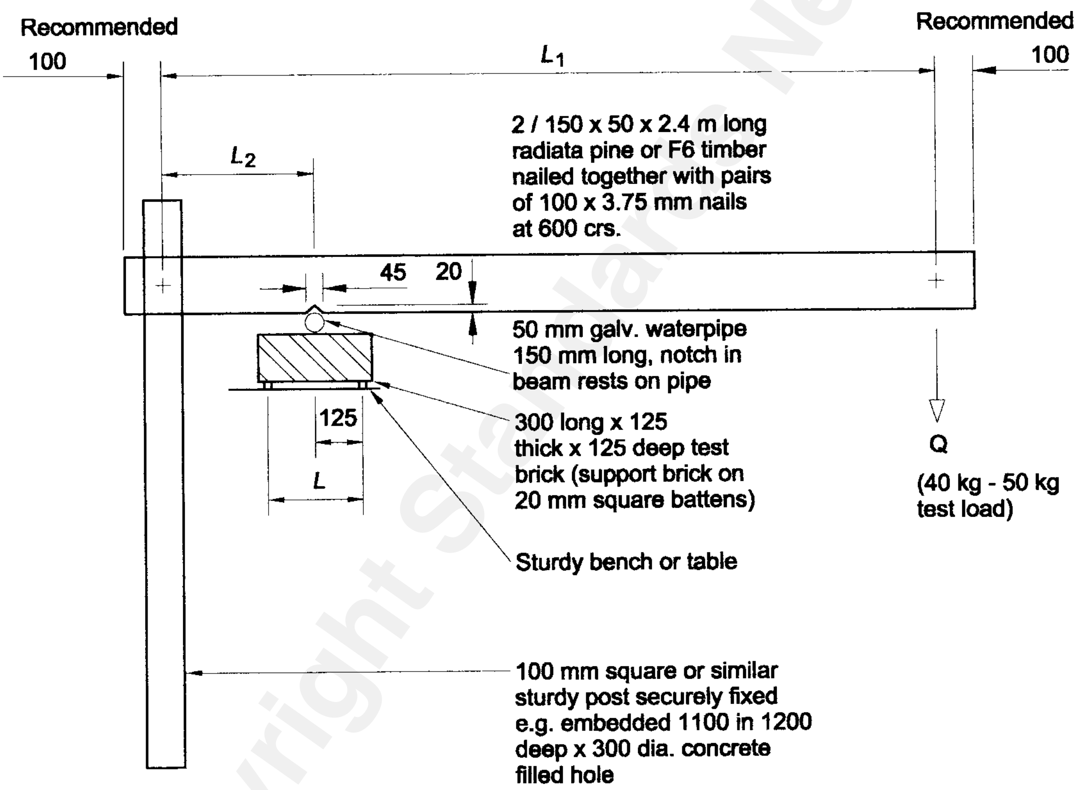
L_1, L_2	as defined in figure J2
Q	the test failure load (kg)
G	the weight of the beam (kg)

other symbols as defined in J1.3.

CJ2.3

As an example where:

$L = 0.250$ m
$L_1 = 2.2$ m
$L_2 = 0.4$ m
$b = 0.150$ m
$d = 0.125$ m



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 stronger beam, fixings, table and hold- down.

(3) The outer end of the lever shall be horizontal when the load is applied.

Figure J2 – Lever rupture test

APPENDIX K
REQUIREMENTS ADDITIONAL TO SECTION 2 FOR *IN SITU* ADOBE and COB
(Informative)

K1 GENERAL
In situ adobe and cob are essentially the same technique, except that *in situ* adobe uses a mould to hold the material as it is first placed upon the wall whereas cob is generally a "mouldless" technique.

This Appendix recognizes that direct on-the-wall mortarless earth building methods are currently being used in New Zealand. At the time of writing this Standard there are successful examples of these construction methods which have been completed, but not enough work has been done to date to be able to confidently standardize all criteria.

In situ adobe is a mortarless method of earth building whereby a suitable earth mix is cast into its final position by placing the mix into a brick mould placed on the wall under construction. The mould is removed immediately leaving the brick surface to be worked up into a monolithic wall with the desired surface finish as it hardens.

Cob is the method of building whereby a lump of a suitable sandy clay/straw earth mix is mixed up and placed into the wall without using a mould, to form a monolithic wall that is bonded to other cobs and the surface trued up and finished as the material dries.

A modern tradition is starting to emerge which suggests that *in situ* adobe is usually a mix with a stabilizer in it, and cob is a more traditional clay/sand/straw mix.

The success of both of these methods of construction relies heavily upon selecting a soil mix that virtually eliminates the shrinkage that is inherent with both these methods of construction. This means that successful soils for these techniques generally contain a low proportion of clay in the mix.

This is generally a lower clay content than conventional adobe (mud) brick. Whereas cured adobes have shrunk before being laid, with *in situ* adobe and cob 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.

An ideal mix will have just sufficient clay in it to bind together sand particles in the mix with minimal shrinkage. Shrinkage may be overcome by modifying the earth mix, by limiting the size of cast units, or by sealing shrinkage cracks at a later date if there is no risk of loss of structural integrity. The use of cement or hydrated lime may also help reduce shrinkage in some soils.

In situ adobe is formed by placing a wet sandy adobe-like soil mix into a mould set up in place on a wall. The moulds are removed immediately after brick casting takes place.

K3 COB MANUFACTURE
Cob is made by making and placing lumps of a stiff sandy adobe-like soil mix into place on a wall where they are stamped or tamped together.

The joints and the surface are "worked" as the mixture sets and cures to form a monolithic wall giving the desired surface finish of either fair finish or suitable for rendering. Successive courses are added without mortar to form either structural, loadbearing walls or free standing or infill walls which are not necessarily performing a significant structural function.

Admixtures such as cement, hydrated lime, straw, or bitumen emulsion may be used.

Surface coatings may be used to enhance durability although this is outside the scope of this Standard. (See Appendix L).

The soil mix should be soaked for at least 12 hours before moulding, unless cement is included in the mix, in which case the mix can be mixed up from dry.

Preceding layers must be allowed to stiffen before successive layers are cast. The weight of new work should not be such as to displace or deform proceeding work by more than 10 mm in any direction, unless slumping is desired for aesthetic reasons and does not cause collapse or cracking.

The surface of previous work should be thoroughly wetted immediately prior to placing of subsequent work. This helps prevent premature drying at the joint and improves bond strength.

Depending on the thickness of the wall, and its weather exposure, curing can take from one week to several months. Excessive exposure to direct sun or strong wind can cause uneven drying and consequential cracking.

Solid walls can be manufactured in a wide range of sizes and dimensional proportions.
The 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 may 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.

K4 MOULDS (*In situ* adobe)
Moulds should be shaped to allow for the units to be cast and the moulds removed without damage to the cast unit or adjacent work. The moulds have no top or bottom. They are typically made from sheet metal or thin steel, and may have slightly tapering sides to ease the removal of the mould from the contained material.

K5 PREFERRED SIZES
There are no preferred sizes, although cast units should not be longer than around 450 mm. Consistency in cast unit thickness has an influence on the level of successive courses. In a commercial environment the amount of dimensional variation allowed could be nominated.

K6 BONDING
The earth is required to bond to previous layers and adjoining surfaces are roughened and keyed to improve bond.

In situ bricks are cast in an overlapping bond pattern generally using a half bond where possible, and 100 mm minimum bond otherwise.

Cob is laid up in an overlapping pattern that provides as much bonding with previous and adjacent cobs as possible generally using overlaps of a half bond where possible. A recommended method for keying is to form 50 mm deep by 35 mm diameter holes in the top surface at 100 mm centres.

Another method recommended for laying cobs of a stiffer consistency is to place the cobs on the wall in a herring bone pattern, aligning the cobs between 45° and 60° to the plane of the wall. Courses are laid with layers alternating in their alignment.

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

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

K7 SHRINKAGE CONTROL USING CONSTRUCTION JOINTS

Vertical construction joints to control horizontal shrinkage shall be provided as required by 2.12 for adobe brick. Any construction joints should be detailed to resist weather ingress.

Walls made by these methods may also shrink significantly vertically 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.

K8 TESTING

K8.1 Shrinkage

The success of this method of construction relies heavily on control of shrinkage and must be specifically assessed for each project. A suggested limit for shrinkage would be 0.1 % over a 600 mm sample measured as per adobe mortar shrinkage in Appendix F. Ideally a test panel would be tried before full scale wall construction commences.

Samples for compression testing or flexural tensile testing or robustness (drop) testing can be cast into moulds as for adobe. These can be tested using the methods of Appendices H and J.

K8.2 Bond strength test

If there is concern about bond strength then a suitable test must be performed as per Appendix A3.1.

K8.3 Durability

Tests for durability are performed on purpose made bricks made from representative samples of the

APPENDIX L
SURFACE COATINGS
(Informative)

L1 GENERAL
Although surface coatings may be used to enhance the durability of earth building materials, such enhancement is outside the scope of this Standard as a means of compliance with the materials and workmanship requirements of structures designed in accordance with either or both of NZS 4297 and NZS 4299. Durability enhancement based on this Appendix may form part of an alternative solution to clause B2 of the New Zealand Building Code and as such will need to be to the satisfaction of the territorial authority.

Surface coatings may be used to enhance the durability of materials which are not excluded by 2.1.1.2 but shall not be used to make unacceptable materials able to be used.

L2 PURPOSES OF SURFACE COATINGS
Surface coatings may be used:

(a) To prevent moisture penetration;

(b) To prevent erosion and reduce surface dusting;

(c) To bind the surface layers for colouring and for modifying wall surface texture;

(d) For aesthetic reasons.

Where building design or climatic conditions suggest the need to improve the level of durability of a particular earth building material, this may be achieved by either:

(a) Full stabilization of the earth used in the exterior walls; or

(b) The use of appropriate surface coatings.

L3 SURFACE PREPARATION
A surface which is to have a coating applied shall be prepared in a manner appropriate to the coating being used.

L4 PROPERTIES REQUIRED OF COATING

(a) A surface coating shall exclude the entry of water but permit the exit of water vapour from the underlying earth wall material i.e. "breathe freely". It shall not form a film impervious to air.

(b) It shall provide protection by stabilization of soil particles at the outside surface of the wall.

(c) The surface coating shall be resistant to degradation by ultraviolet light.

(d) When tested on representative sample of earth building material, it shall demonstrate an improvement in durability performance to a level appropriate to the intended exposure of the wall being constructed.

L5 SURFACE COATINGS

L5.1 Unsuitable material

Use of earth material that fails the wet/dry appraisal test as set out in Appendix C of this Standard or fails the erosion tests of Appendix D or E does not comply with this Standard whether a surface coating is applied or not.

The use of such material is subject to specialist appraisal under the alternative solutions provisions of the New Zealand Building Code.

L5.2 Improvement of erodibility index by surface coatings

It is recommended that the erodibility index of a material be improved by a maximum of 1 unit by the application of a surface coating subject to a suitable re-testing result.

Improving the erodibility index by the use of a surface coating is outside the scope of this Standard and is subject to specialist appraisal under the alternative solutions provisions of the New Zealand Building Code.

L5.3 Limits on erodibility index improvement

It is further recommended that a sample with an erodibility index of 2 after testing with either the spray test (Appendix D) or the drip test (Appendix E) may only be given an erodibility rating of 1 after the application of a surface coating and subject to a suitable test result using the spray test.

A sample of material that gives an erodibility index test result of 3 or 4 for example could have its erodibility index rating upgraded to 2 or 3 respectively subject to a suitable test result after the application of a surface coating. Although this provision may well be regarded as conservative, the results of failure of a surface coating can be spectacular if the durability of the building is relying solely on the integrity of that surface coating.

L5.4 Performance of various coating types

Traditional earth, lime and gypsum based coatings are generally very compatible with earth surfaces. The use of bitumen emulsion in earth based surface coatings also has a reasonably successful track record (although the colour of the surface may not be very acceptable without further coatings).

Chemical treatments based on silicones, silicates, water and oil based coatings or paints, or cement based or cement stucco based renders can vary widely in their performance on different soils or different soil mixtures and their performance may be unpredictable. Thick surface coatings that do not penetrate the wall surface such as cement stucco require mechanical attachment that requires specific design which includes an assessment of permeability to water vapour of both the cement render and any paint treatment that it may be given.

work very well, while others may fail when moisture gets behind them and be sloughed off carrying the whole surface with them.

Sometimes a coating that performs well on one soil may not do so on another.

L6 CURING AND DRYING OF SURFACE COATINGS

All surface coatings are to be properly cured and dried.

Most earth, lime and gypsum renders or coatings require slow controlled drying to ensure maximum adhesion and minimal cracking. Not working in direct sun, and the provision of shade and/or lightly spraying with water is recommended.

L7 MAINTENANCE

Surface coatings will not be expected to maintain protection for the life of the structure without maintenance but may require periodic maintenance to restore the necessary properties when they become degraded.

L8 PERMEABILITY

It is important that surface coatings have adequate permeability to allow moisture within the wall to be released and prevent its accumulation.

L9 COATING TYPES

L9.1 External and wet area coatings

Water resisting coatings to prevent erosion and moisture penetration of external walls and internal wet areas in increasing order of impermeability include:

(a) Bagging;

(b) Earth plasters with natural additions;

(c) Lime plasters;

(d) Whitewash or limewash;

(e) Oil based paints;

(f) Boiled linseed oil;

(g) Breathable silicone sealants;

(h) Water based paints;

(j) Cement render or plaster.

L9.2 Dust reducing coatings

Internal dust reducing finishes include:

(a) Wallpaper size;

(b) Earth renders and plasters with natural additives;

(c) Lime plasters;

(d) Gypsum plasters;

(e) Whitewash or limewash;

(f) Boiled linseed oil;

(g) Water based paints;

(h) PVA preparations;

(j) Oil based paints;

(k) Cement plasters.

L9.3 Higher maintenance or longer life coating choices

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

More permanent, waterproof surfaces are more expensive initially and may create higher long term maintenance costs. Waterproof surfaces, such as cement plaster, can contain and trap moisture, while naturally surfaced earth walls will absorb and give off airborne moisture allowing the wall to breathe.

L10 UNTREATED SURFACES

Rammed earth and earth brick walls may be left untreated on both internal and external surfaces and be most satisfactory, particularly external surfaces.

Some internal earth walls particularly unstabilized adobe may attract dust and may benefit from a surface coating.

L11 BAGGING

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

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

Recommended mixes are:

- 50 % fresh cow manure and 50 % sandy clay and at the consistency of oil based paint.

The walls should be sprayed lightly with water and bagging done whilst the wall is still damp.

L12 EARTH PLASTERS

Earth plaster is a traditional treatment for adobe walls and is normally applied in 2 coats both for exterior and interior surfaces.

The first coat of screened fine sandy clay is usually reinforced with straw or fibrous material and applied approximately 10 mm thick. The second coat is also fine screened clay but is applied as thinly as possible.

Natural additives including cow manure or rye flour, which increase surface hardness, may also be added to the earth plaster.

including skimmed milk, casein and tallow.

Old lime and new limewashes are very compatible.

Reference should be made to The Earthbuilders Encyclopaedia for more details. Whitewash should be applied to clean dust free surfaces in at least 2 or 3 coats.

L14 GYPSUM PLASTERS

Gypsum plasters are suitable for interior earth walls to provide a very smooth surface finish. Gypsum plasters are usually applied in 2 coats with the first coat typically 20 mm thick and the second coat 3 mm to 5 mm thick.

Recommended mixes are:

(a) First coat - 1 part gypsum plaster with fibre reinforcing
- 5 parts sand

(b) Second coat - 1 part of lime putty mixed with plaster of paris
- 2 parts sand.

L15 LIME PLASTERS

Lime plasters are also suitable for interior earth walls to provide a smooth surface finish and are usually applied in 2 coats similar to gypsum plasters.

Recommended mix is:

1 part lime putty
5 parts sand
1 part screened clay soil.

L16 CEMENT PLASTERS

Cement plasters can provide a weatherproof surface that if properly applied should have a maintenance free life of 10 to 15 years. However cement plasters do have a principal disadvantage in that they have a different coefficient of expansion than earth which may lead to separation of the 2 surfaces. Stucco netting which is mechanically attached to the earth substrate is usually provided with cement plasters.

For more detail on cement plasters, including mixes and application procedures, reference should be made to P McHenry's book Adobe and Rammed Earth Buildings and to The Earthbuilders Encyclopaedia.

Cement or stucco plaster shall not be applied to adobe walls until at least 3 months after laying. Refer to NZS 4251 and to Good Stucco Practice published by BRANZ.

APPENDIX M
EARTH FLOORS
(Informative)

M1 GENERAL

M1.1
This section deals with the performance criteria for earth floors in single unit dwellings only, or buildings with traffic or loading conditions that are similar.

This Appendix gives guidance on matters which are required to be covered in drawings and specifications for earth floors. Such designs will need to be to the approval of the territorial authority.

Earth floors have an established tradition and have historically been made in a number of ways.

Some traditional earth floors are relatively soft, and subject to damage by shoes, heavy foot traffic, or abrasion by furniture movement. However they have performed well as long as the owners have been prepared to accommodate this by not subjecting the floor to frequent impact from furniture or hard footwear. Earth floors have also usually been easily repaired with regular maintenance of surface coatings.

M1.2 Scope
This section deals with floors that are made from:

(a) Pressed earth brick;

(b) Adobe brick;

(c) Rammed earth;

(d) Poured earth.

M2 PERFORMANCE CRITERIA
Earth floors shall be substantially level, have adequate resistance to abrasion, compression, impact and slipping, and be healthy.

M3 CONSTRUCTION

M3.1 Movement joints
Provision shall be made to accommodate movement due to shrinkage expansion or settlement of the

threshold between 2 rooms. Joints shall be immediately over and be continuous with movement joints and contraction joints in the base. This procedure may not be acceptable if the base joints are not true, for example, not straight and parallel, or if their layout does not coincide with that of the floor. In these circumstances, guidance should be sought from the building designer.

M3.2 Thermal effects
Light-coloured floors reflect and radiate heat, dark-coloured floors mainly re-radiate heat only and therefore absorb and conduct a high proportion of solar heat gain to the backing. Consideration should be given to sub-floor insulation to enhance the thermal performance of an earth floor. These characteristics may be used in the design of thermally efficient buildings.

Where it is suspected that thermal movement of the floor may be excessive, special precautions such as provision of movement joints should be considered.

M3.3 Admixtures
One solution to the problem of preserving and protecting earth floors against erosion is the use of admixtures. These come in the form of lime, cement, bitumen, fly ash, and many other products.

M3.4 Sealants or surface coatings
Surface coatings may be used as a waterproof covering such as natural products, chemical products, and combinations of products which form an external protection against earth floor wear and resistance to penetration by water or other fluids.

M4 FUNCTIONAL CONSIDERATIONS

M4.1 Functional considerations
Material for earth floors may be stabilized or have surface coatings or hardeners applied to enhance the performance of an earth floor with respect to abrasion resistance, compressive strength, impact resistance, or resistance to penetration by water or other fluids.

M4.2 Stabilizers
Stabilizers for earth floors usually consist of bitumen emulsion, cement, or lime. Sometimes fly ash, or other less common products are used. Stabilizers should be used in accordance with all relevant provisions of this standard.

M4.3 Sealants or surface coatings
Surface coatings for earth floors may consist of materials such as natural oils or waxes, or other proprietary sealants or products. Tests for suitability should be carried before application. Note that some surface coatings can change the colour of a floor significantly.

M5 TOLERANCES ON LEVEL AND SURFACE FINISH

M5.1 General
Flatness or surface regularity is a measure of the deviations from a plane over a large area of the floor, as well as over small local areas. Some variations in surface level can be allowed without detriment to the satisfactory performance of the floor and the permissible limits associated with these variations will depend on many factors.

M5.2 Surface finish
The tolerances of surface finish should take into account the method used to lay the floor. Methods based on laying bricks with substantial thickness of bed will allow some adjustment of the surface regularity, whereas bricks laid on thin beds will allow minimal correction.

M5.3 Departure from datum
The maximum departure from the finished floor level should be specified, taking into account the area of the floor and its use.

Recommended tolerances for floor levels:

(a) Floor level is to be generally within ±15 mm of the level indicated on drawings;

(b) Within one room the variation from corner to corner shall be not more than ±15 mm;

(c) The variation over a 2 m long straight edge shall be no more than ±10 mm.

Greater accuracy to datum may be needed in small rooms, along the line of partition walls, in the vicinity of door openings and where specialised equipment is to be installed directly on the floor.

M5.4 Safety
To be safe the floor shall be without sharp changes in height (e.g. between different surfaces or between individual bricks) of more than ±5 mm over a 300 mm straight edge.

M6 MOISTURE CONTROL

M6.1 Rising damp
A membrane damp proof course installed over compacted hardfill to the requirements of NZS 3604 is required to control rising damp.

Compliance with M6.1 is required to meet the requirements of clause E2.3.3 of the New Zealand Building Code.

M7 SETTLEMENT AND CRACKING

M7.1 Earth floors: General

M7.1.1
Settlement of parts of a building must not induce unacceptable cracking in earth floors.

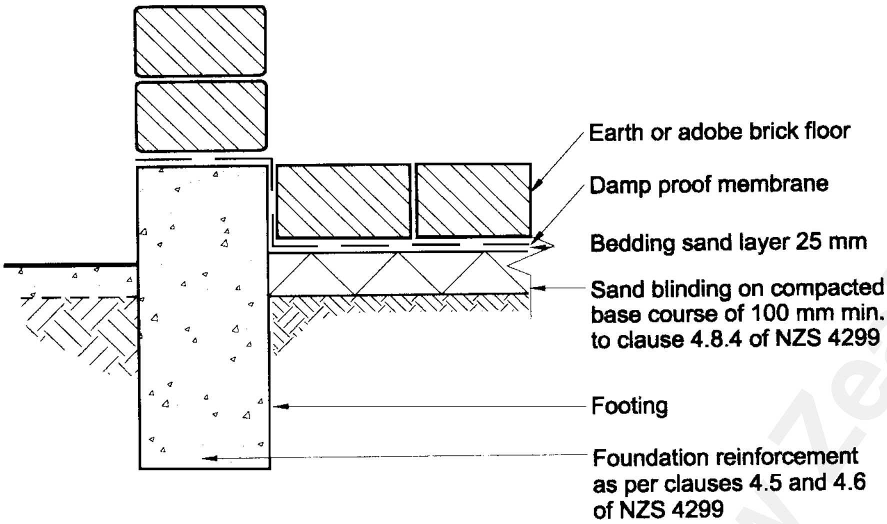
M7.1.2
Floors are to be structurally independent of the walls to avoid excessive cracking due to wall loadings and settlement of footings. Figures M1, M2 and M3 show some acceptable construction sequences to follow when installing earth floors.

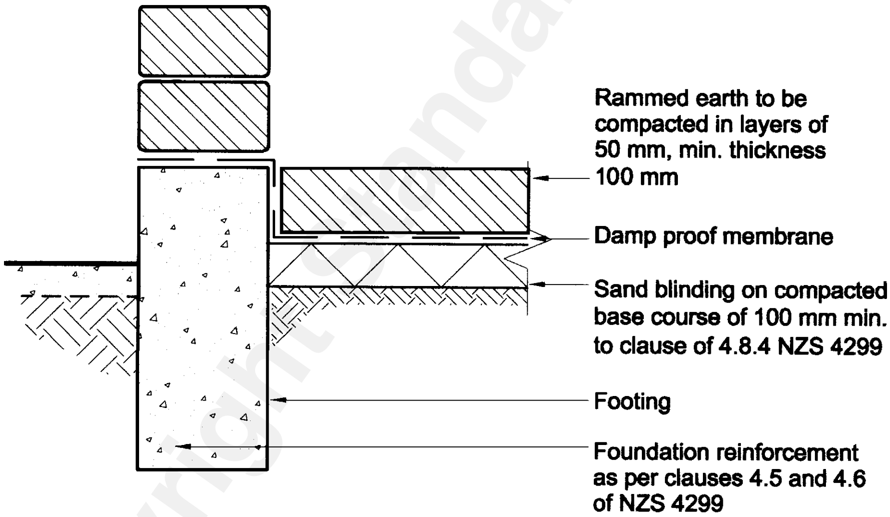
M7.2 Cracking
Cracking is expected to occur in rammed earth and poured earth floors and some joint cracking may occur in adobe floors. As the floor is not a structural element this cracking is not of structural significance. It is desirable to confine the location of cracking along preferred lines. Figure M3 illustrates how cracking

of the floor.

Maximum gap between bricks is recommended to be 3 mm if ungrouted, 20 mm if grouted.

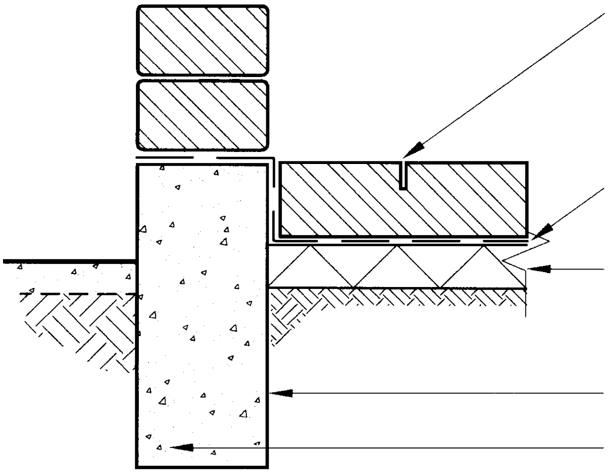
The minimum thickness is recommended to be 75 mm for pressed brick and 100 mm for adobe. The maximum length of any brick in an earth floor is recommended to be 450 mm.





NOTE -
No reinforcing / steel mesh required in earth floor.

Figure M2 – Rammed earth floor



NOTE -
(1) No reinforcing / steel mesh required in earth floor.
(2) No significant amount of bedding sand required. However, a light dusting by hand wil give added protection for the membrane.

APPENDIX N
PRESSED BRICK LAYERING TEST

(Normative)

N1 SAMPLING

Out of every 2500 bricks a sample of either 5 or 3, in accordance with table 2.1, shall be taken. The sample bricks shall be broken in half by bending perpendicular to the plane of compression.

N2 EXAMINATION

The broken faces shall be examined for layering or for evidence of uneven mixing the presence of either or both indicates an unacceptable brick.

CN2

Variations of colour or texture between one part of the broken surface and another or the obvious layering of material within the brick indicates unacceptable mixing.

N3 ACCEPTANCE CRITERIA

The whole 2500 brick batch shall be condemned if the total number of unacceptable bricks equals 2 or more.

NOTES

NOTES

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