NEW ZEALAND
EDICT OF GOVERNMENT

In order to promote public education and public safety, equal justice for all, a better informed citizenry, the rule of law, world trade and world peace, this legal document is hereby made available on a noncommercial basis, as it is the right of all humans to know and speak the laws that govern them.


We will sell to no man, we will not deny or defer to any man either justice or right. Magna Carta—Tūtōhinga Nui
Kore rawa e hoko ki te tangata, e kore e whakakahorehia, e tautuku rānei te tangata ki te ture, tika ranei.
Earth Buildings Not Requiring Specific Design
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 representatives of the following organizations:

Hugh Morris Auckland University
Miles Allen Earth Building Association of New Zealand
Thijs Drupsteen Earth Building Association of New Zealand
Bob Gilkison Earth Building Association of New Zealand
Graeme North Earth Building Association of New Zealand (Chair)
Richard Walker Institution of Professional Engineers New Zealand
Min Hall New Zealand Institute of Architects
Jenny Christie Victoria University of Wellington

© COPYRIGHT

The copyright of this document is the property of the Standards Council. No part of it may be reproduced by photocopying or by any other means without the prior written permission of the Chief Executive of Standards New Zealand unless the circumstances are covered by Part III of the Copyright Act 1994.

Standards New Zealand will vigorously defend the copyright in this Standard. Every person who breaches Standards New Zealand’s copyright may be liable to a fine not exceeding $50,000 or to imprisonment for a term not to exceed three months. If there has been a flagrant breach of copyright, Standards New Zealand may also seek additional damages from the infringing party, in addition to obtaining injunctive relief and an account of profits.

Published by Standards New Zealand, the trading arm of the Standards Council, Private Bag 2439, Wellington 6020.
Telephone: (04) 498 5990, Fax: (04) 498 5994.
E-mail: snz@standards.co.nz
Website: www.standards.co.nz

<table>
<thead>
<tr>
<th>No</th>
<th>Date of issue</th>
<th>Description</th>
<th>Entered by, and date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>December '99</td>
<td>Provides enhanced provisions for the foundation provisions of NZS 3604:1999. Some over-designed details are amended to be more economic.</td>
<td>in this reprint</td>
</tr>
</tbody>
</table>
CONTENTS PAGE
Committee representation ........................................................ IFC
Copyright ................................................................................... IFC
Related documents ....................................................................... 7
Foreword ................................................................................... 8

Section
1 SCOPE AND INTERPRETATION
  1.1 Scope and objective ................................................ 11
  1.2 Limitations ............................................................... 11
  1.3 Building components ............................................... 14
  1.4 Interpretation ........................................................... 15
  1.5 Definitions ................................................................ 16

2 GENERAL
  2.1 Materials ................................................................. 21
  2.2 Methods of construction .......................................... 22
  2.3 Earthquake zones ................................................... 22
  2.4 Wind zones .............................................................. 22
  2.5 Durability ................................................................ 24
  2.6 Snow loads .............................................................. 27
  2.7 Concrete durability .................................................. 29
  2.8 Materials testing ...................................................... 29
  2.9 Thermal insulation ................................................... 30
  2.10 Protection of earth walls from external moisture .... 31

3 SITE REQUIREMENTS
  3.1 Soil bearing capacity and site profile requirements 32
  3.2 Soil types ................................................................. 34
  3.3 Bearing .................................................................... 34
  3.4 Site drainage and flood avoidance ......................... 34
  3.5 Site preparation ....................................................... 35

4 FOOTINGS
  4.1 General ................................................................. 35
  4.2 Width of footing ....................................................... 35
  4.3 Depth of footing ...................................................... 36
  4.4 Height of footing ...................................................... 36
  4.5 Reinforcement of footings ....................................... 37
  4.8 Concrete slab on ground floors ............................... 40
  4.9 Damp proof course .................................................. 41
  4.10 Splashback course .................................................. 41
  4.11 Footing construction details ................................... 41

5 WALLS
  5.1 General ................................................................. 43
  5.2 Wall systems to resist vertical loads ......................... 44

Contents continued overleaf
5.3 Earth wall systems to resist horizontal loads .......... 44
5.4 Bracing demand for reinforced earth walls
   where earthquake zone factor > 0.6 ...................... 48
5.5 Bracing demand for reinforced earth walls
   where earthquake zone factor ≤ 0.6 ..................... 54
5.6 Bracing demand for unreinforced earth walls
   where earthquake zone factor ≤ 0.6 ..................... 54
5.7 Partially reinforced walls .................................. 55
5.8 Reinforcement of earth walls
   280 to 350 mm thick ........................................ 58
5.9 Reinforcement of rammed earth walls 280 to
   350 mm thick .................................................. 61
5.10 Earth walls without structural diaphragms ............ 63
5.11 Connection between walls and top plates or
   bond beams ..................................................... 65

6  STRUCTURAL DIAPHRAGMS
   6.1 General ......................................................... 65
   6.2 Ceiling and roof diaphragms ............................. 66
   6.3 Floor diaphragms ............................................ 66
   6.4 Diagonal sarking ............................................ 67
   6.5 Sheet sarking ............................................... 67
   6.6 Sheet flooring ............................................... 67
   6.7 Connections of diaphragms to earth walls ............ 68
   6.8 Openings in diaphragms ................................. 68

7  BOND BEAMS
   7.1 General ......................................................... 73
   7.2 Bond beams with structural diaphragms .............. 73
   7.3 Bond beams without structural diaphragms .......... 74
   7.4 Intersection of timber bond beams .................... 76
   7.5 Laps in reinforcement of concrete bond beams ..... 77
   7.6 Size of reinforcement of concrete bond beams ...... 77
   7.7 Intersection of concrete bond beams .................. 79
   7.8 Gable shaped walls ....................................... 79
   7.9 Timber gable end walls above earth walls .......... 79

8  LINTELS
   8.1 General ......................................................... 80
   8.2 Timber lintels .............................................. 80
   8.3 Concrete lintels ............................................ 82

9  WALL OPENINGS AND FIXINGS
   9.1 Anchoring of joinery frames to walls ............... 89
   9.2 Door and window details ................................ 89
   9.3 Fixings for timber framed walls ..................... 93
   9.4 Arches ......................................................... 95
   9.5 Roof tie down bolts ..................................... 95
   9.6 Flashings ...................................................... 97
10 CONTROL JOINTS

10.1 General .................................................................... 97
10.2 Control joints for rammed earth walls ..................... 97
10.3 Control joints for adobe and pressed brick walls .... 99

11 CINVA BRICKS

11.1 Scope .................................................................... 100
11.2 Foundations ........................................................... 100
11.3 Bracing walls ......................................................... 101
11.4 Wall reinforcing ...................................................... 101
11.5 Cinva brick walls without structural diaphragms ... 102
11.6 Structural diaphragms ........................................... 102
11.7 Concrete bond beams ........................................... 102
11.8 Lintels .................................................................... 103
11.9 Wall openings and fixings ..................................... 104
11.10 Control joints ......................................................... 105

Appendix

A Derivation of tables .......................................................... 106
B Worked examples ............................................................ 110

Figure

1.1 Building types covered by this Standard....................... 13
2.1 Earthquake zone factors ............................................. 23
2.2 Definition of eaves height and eaves width ................. 27
2.3 Durability design ......................................................... 28
3.1 Relationship of foundation to sloping ground surface .... 32
4.1 Footing dimensions and general details ..................... 37
4.2 Footing reinforcement where earthquake zone
factor ≤ 0.6 ................................................................. 38
4.3 Footing reinforcement where earthquake zone
factor > 0.6 ................................................................. 38
4.4 Reinforcement at footing or bond beam intersections .... 39
4.5 Alternative strip footing type E detail with fired brick
facing ...................................................................... 41
4.6 Footing type F with concrete floor slab ...................... 42
4.7 Footing type G with concrete floor slab and fired
brick facing .............................................................. 42
4.8 Footing with concrete floor slab and concrete
block facing ............................................................. 43
5.1 Determination of bracing demand
5.3 Bracing line support system and openings at
external corners .......................................................... 47
5.4 Reinforcing and dowels for reinforced and partially
reinforced earth walls .................................................. 57
5.5 Horizontal reinforcement for reinforced earth walls,
Types A and B ........................................................... 59
5.6 Horizontal reinforcement for reinforced earth walls,
Type C ....................................................................... 60
5.7 Reinforced rammed earth walls with concrete columns .... 61

Contents continued overleaf
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.8</td>
<td>Reinforcement of reinforced rammed earth walls with concrete columns at corners and short return walls</td>
</tr>
<tr>
<td>5.9</td>
<td>Reinforcement of rammed earth walls with concrete columns under window openings</td>
</tr>
<tr>
<td>5.10</td>
<td>Layout of earth walls with concrete bond beams and without a structural diaphragm</td>
</tr>
<tr>
<td>6.1</td>
<td>Sheet sarking diaphragm</td>
</tr>
<tr>
<td>6.2</td>
<td>Diaphragm fixing details</td>
</tr>
<tr>
<td>6.3</td>
<td>Connection of diaphragms to walls</td>
</tr>
<tr>
<td>6.4</td>
<td>Connection of ceiling diaphragms to earth walls for batten joists or trusses</td>
</tr>
<tr>
<td>6.5</td>
<td>Connection of ceiling diaphragms to earth walls for sloping ceilings on underside of trusses</td>
</tr>
<tr>
<td>6.6</td>
<td>Location of openings in diaphragm</td>
</tr>
<tr>
<td>7.1</td>
<td>Connection of timber bond beams or top plates with structural diaphragms (plan)</td>
</tr>
<tr>
<td>7.2</td>
<td>Connection of timber bond beams or top plates without structural diaphragms (plan)</td>
</tr>
<tr>
<td>7.3</td>
<td>Concrete bond beams</td>
</tr>
<tr>
<td>7.4</td>
<td>Timber bond beam for timber gable end walls above earth walls</td>
</tr>
<tr>
<td>8.1</td>
<td>Timber lintels supporting timber framing above</td>
</tr>
<tr>
<td>8.2</td>
<td>Timber lintels supporting earth walls at gable ends</td>
</tr>
<tr>
<td>8.3</td>
<td>Concrete lintel general arrangement</td>
</tr>
<tr>
<td>8.4</td>
<td>Concrete lintel sizes and reinforcement</td>
</tr>
<tr>
<td>8.5</td>
<td>Load cases for concrete lintels</td>
</tr>
<tr>
<td>8.6</td>
<td>Concrete lintel within and outside middle 2/3 of bond beam span</td>
</tr>
<tr>
<td>9.1</td>
<td>Anchors for door, window and timber partition frames for earth brick walls</td>
</tr>
<tr>
<td>9.2</td>
<td>Window head details</td>
</tr>
<tr>
<td>9.3</td>
<td>Window jamb details</td>
</tr>
<tr>
<td>9.4</td>
<td>Window sill details</td>
</tr>
<tr>
<td>9.5</td>
<td>Fixing of timber framed walls to allow for adobe earth wall vertical shrinkage</td>
</tr>
<tr>
<td>9.6</td>
<td>Arch at door or window opening</td>
</tr>
<tr>
<td>9.7</td>
<td>Roof tie down detail</td>
</tr>
<tr>
<td>10.1</td>
<td>Control joint for rammed earth walls</td>
</tr>
<tr>
<td>10.2</td>
<td>Horizontal construction joint for rammed earth walls</td>
</tr>
<tr>
<td>10.3</td>
<td>Control joint for adobe and pressed brick</td>
</tr>
<tr>
<td>11.1</td>
<td>Cina brick wall footings</td>
</tr>
<tr>
<td>11.2</td>
<td>Type D horizontal reinforcing (cina brick only)</td>
</tr>
<tr>
<td>11.4</td>
<td>Cina brick lintels</td>
</tr>
<tr>
<td>11.5</td>
<td>Direct fixed rafters</td>
</tr>
<tr>
<td>11.6</td>
<td>Cina brick wall control joint – plan view</td>
</tr>
<tr>
<td>B1</td>
<td>Example 1 building</td>
</tr>
<tr>
<td>B2</td>
<td>Example 1 building – Vertical reinforcement layout</td>
</tr>
<tr>
<td>B3</td>
<td>Example 2 unreinforced earth building</td>
</tr>
<tr>
<td>B4</td>
<td>Example 2 building – Wall and dowel layout</td>
</tr>
<tr>
<td>B5</td>
<td>Example 3 partially reinforced earth building</td>
</tr>
<tr>
<td>B6</td>
<td>Example 3 building – Vertical reinforcement layout</td>
</tr>
</tbody>
</table>

---

**Note:** The table above is a summary of the contents of the NZS 4299:1998 document. It includes section numbers and brief descriptions of the topics covered in each section. This summary is intended to provide a natural representation of the document's structure and content.
Table

2.1 Building wind zones ........................................................... 24
2.2 Site specific building limiting erodibility indices for different wind zones, wall exposures, eaves heights and widths in areas with up to 2000 mm per year average rainfall................................................................. 26
2.3 Earth wall construction for thermal performance ................. 30
2.4 Exterior moisture protection for earth walls ....................... 31
5.1 Bracing demand for bracing support lines for single storey earth walls and light roof and earthquake zone factor > 0.6 ............................................................. 49
5.2 Bracing demand for bracing support lines for single storey earth walls and heavy roof and earthquake zone factor > 0.6 ............................................................. 50
5.3 Bracing demand for bracing support lines for single storey earth walls and timber part storey and light roof and earthquake zone factor > 0.6 ......................... 51
5.4 Bracing demand for bracing support lines for single storey earth walls and timber second storey and light roof and earthquake zone factor > 0.6 ......................... 52
5.5 Minimum bracing demand per square metre for earthquake zone factor > 0.6 ......................................................... 53
5.6 Bracing capacity of reinforced earth walls ......................... 54
5.7 Bracing capacity of unreinforced earth walls ..................... 55
5.8 Bracing capacity of partially reinforced earth walls .......... 56
5.9 Spacing of vertical D 12 reinforcement in earth walls....... 58
5.10 Spacing of vertical D12 reinforcement in rammed earth walls without horizontal reinforcement................. 59
5.11 Length of return walls for bond beam supported walls ...... 65
6.1 Connection of structural diaphragm to timber bond beam. 68
7.1 Bond beams with structural diaphragms where earthquake zone factor ≤ 0.6 ........................................................... 74
7.2 Bond beams with structural diaphragms where earthquake zone factor > 0.6 ........................................................... 74
7.3 Bond beams without structural diaphragms where earthquake zone factor ≤ 0.6 ........................................................... 75
7.4 Bond beams without structural diaphragms where earthquake zone factor > 0.6 ........................................................... 76
7.5 Timber bond beams at timber gable end walls above earth walls ................................................................. 79

11.1 Maximum spacing of vertical reinforcement in cinva brick walls ................................................................. 101
11.2 Cinva brick lintels clear opening spans ............................ 104
A1 Design strengths (MPa) .................................................. 106
A2 Strength reduction factors ................................................ 106
A3 Basic load data ................................................................. 107
B1 Summary of bracing demand for example one ................. 113

Contents continued overleaf
RELATED DOCUMENTS

Reference is made in this Standard to the following:

NEW ZEALAND STANDARDS

AS/NZS 2904:1995 Damp-proof courses and flashings

NZS 3101:- – – - Concrete Structures Standard
   Part 1:1995 The design of concrete structures

NZS 3109:1997 Concrete construction

NZS 3402:1989 Steel bars for the reinforcement of concrete

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

NZS 3602:1995 Timber and wood-based products for use in building

NZS 3603:1993 Timber Structures Standard

NZS 3604:1999 Timber frame building construction

NZS 3631:1988 New Zealand timber grading rules

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


NZS 4218:1996 Energy efficiency – Housing and small building envelope

NZS 4222:1992 Material for the thermal insulation of buildings

NZS 4229:1986 Code of practice for concrete masonry buildings not requiring specific design

NZS 4297:1998 Engineering design of earth buildings

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 lists contained in the monthly magazine Standards issued free of charge to committee and subscribing members of Standards New Zealand.
FOREWORD

General
This standard and the associated NZS 4297 *Engineering design of earth buildings* and NZS 4298 *Materials and workmanship for earth buildings* 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 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 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.

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.

Out-of-plane loading on unreinforced vertically spanning walls has been approached as ultimate limit state design based on the failure 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 many 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 BUILDINGS NOT REQUIRING SPECIFIC DESIGN

1 SCOPE AND INTERPRETATION

1.1 Scope and objective
This Standard sets down design and construction requirements for adobe, pressed earth brick or rammed earth buildings not requiring specific design.

This Standard is intended to be approved as a means of compliance with clauses B1, B2 and E2 of the New Zealand Building Code.

The use of the Standard as a means of compliance with the New Zealand Building Code does not extend to provisions which are in non-specific or unquantified terms (such as where provisions are required to be appropriate, adequate, suitable, similar, satisfactory, acceptable, applicable or the like). Such provisions must be to the approval of the territorial authority.

1.2 Limitations
This Standard applies to buildings within the following limitations:

2 for single storey buildings

(ii) 300 m² per floor for 2 storey buildings.

(c) The height of earth walls shall be limited as follows:

(i) Where the earthquake zone factor $\leq 0.6$ (refer to figure 2.1):

Single storey earth walls with a maximum storey height of 2.75 m and maximum gable wall height of 3.6 m if reinforced and 3.3 m if unreinforced or partially reinforced.
(ii) Where earthquake zone factor > 0.6:

Single storey earth walls with a maximum wall height of 2.75 m and maximum gable wall height of 3.05 m. Unreinforced or partially reinforced earth walls are not permitted.

The storey or wall height is measured from the concrete foundation top, to the underside of the top plate or bond beam for the ground floor and between the floor level and underside of the top plate for the second storey.

Refer to figure 1.1 for illustration of the above.

(d) Building layout above an earth walled ground floor shall be limited to:

(i) A light or heavy roof as defined in 1.5, or

(ii) A timber first floor and a timber walled part storey in the roof space not exceeding 50% of the ground floor, and a light roof, or

(iii) A timber first floor, timber walled second storey up to 2.75 m high and a light roof.

The timber floors of options (ii) and (iii) shall be structural diaphragms.

(e) Earth walls shall be 280 to 350 mm thick except for cinva brick walls which may have a minimum thickness of 140 mm. Exterior walls shall be a minimum of 280 mm thick to provide minimum thermal performance unless additional insulation is provided. The provision of such additional insulation is outside the scope of this Standard.

(f) The roof slope shall not be steeper than 45°;

(g) The design wind speed at the ultimate limit state for the building site, as determined in accordance with this Standard, shall not exceed 50 metres per second;

(h) The basic snow load as specified by NZS 4203 shall not exceed 1.0 kPa;

(j) The annual rainfall shall not exceed 2000 mm per year;

(k) Soil bearing capacity and site profile requirements shall be in accordance with section 3 of this Standard;

(l) The floor live load on suspended floors shall not exceed 1.5 kPa;

(m) Suspended floors and roof shall be of light timber construction complying with the relevant requirements of NZS 3604, unless otherwise modified by this Standard. A structural slab is not required at ground level; however, a wearing surface shall be provided to ensure at all times during

Standard does not describe what is necessary for an earth floor, therefore when one is proposed, full details of its design and maintenance shall be submitted to and approved by the territorial authority.

(n) Concrete foundation members shall be continuous around the perimeter of the building. The foundations of external wing walls may extend outwards from the perimeter foundations by up to 1.2 m. Concrete foundation members under internal walls shall be connected to perimeter members at both ends if longer than 1.2 m but may be connected at one end only if shorter than 1.2 m.

(p) Each part of the building shall be within the limitations stated or implied by the relevant clauses or tables of this Standard;
Figure 1.1 – Building types covered by this Standard

(A) SINGLE STOREY EARTH WALL GABLE ENDS

Light or heavy gable roof

Earth walls with max. gable height
- 3.05 m where Z > 0.6
- 2.75 m where Z ≤ 0.6 for 280 thick unreinforced walls
- 3.30 m where Z ≤ 0.6 for 350 thick unreinforced walls
- 3.60 m where Z ≤ 0.6 for reinforced walls

25° max.

2.75 m max. wall or storey height

0.6 m max. for concrete foundation or slab on ground

(B) SINGLE STOREY HIP ROOF OR TIMBER FRAMED GABLE ENDS

Light or heavy hip roof, or timber gable ends

Timber or concrete bond beam or flat ceiling diaphragm where Z ≤ 0.6.
Ceiling diaphragm or concrete bond beam where Z > 0.6.
Timber bond beam with roof diaphragm as per 7.9 with roof slope 25°

3.6 m max.

As for figure (A)

(C) ONE AND A HALF STOREY BUILDING WITH CEILING DIAPHRAGM AND HIP ROOF OR TIMBER FRAMED GABLE ENDS

Light gable or hip roof

Timber framing with lightweight cladding

Timber floor or ceiling diaphragm

3.6 m max.

As for figure (A)

(D) TWO STOREY

NOTE - Wall or storey height is defined in 1.2.
(q) Some combinations of eave protection, wall height, wind speed and exposure are excluded from the scope of this Standard by 2.5.5;

(r) Earth walled buildings including structural walls of materials other than earth except for non-loadbearing timber framed partition walls, shall be the subject of specific design to NZS 4297;

(s) Earth walls construction shall be either:

(i) All reinforced or,

(ii) Where permitted by 1.2(c)(i), one of:

(A) Partially reinforced

(B) Unreinforced

(C) A mixture of unreinforced and partially reinforced.

C1.2
Any building or part of a building which does not comply with 1.2 is outside the scope of this Standard and will require specific design.

(a) Examples of the types of buildings included are:

NZS 4203 Category IV:
Other buildings such as office buildings, residential buildings, industrial buildings, or warehouses, where not included in any other Category.

NZS 4203 Category V:
Outbuildings, some farm buildings and temporary buildings such as offices on a construction site.

(c) This Standard provides for earthquake-resistant unreinforced earth and partially reinforced walled buildings which will respond elastically to seismic loads, and for reinforced earth walled buildings which will respond with limited ductility.

(g) Wind loadings on earth walls may be disregarded except for cinva brick walls and the design wind speed need not be calculated except in mountainous areas and other areas where there are conditions likely to cause local wind accelerations including valleys and gorges shaped to produce funnelling of the wind, bluffs, very exposed hillsides, peaks and ridges. If there is doubt about the basic non-directional ultimate limit state wind speed not exceeding 50 m/s then reference should be made to specific design methods.

(n) These requirements ensure interconnection of building elements at foundation level. A ground floor slab is not required for this purpose.

1.3 Building components

1.3.1
Buildings constructed in accordance with this Standard shall incorporate structural components of earth, reinforced concrete, and timber. The timber components shall be in accordance with NZS 3604 except for those modifications to floor and roof construction provided by this Standard.
1.3.2
Systems to resist vertical loads shall be the following:

(a) Footings to earth walls to section 4;

(b) Walls
   (i) Internal and external walls to section 5
   (ii) Internal loadbearing timber framed walls supporting timber floors and roofs to NZS 3604 with external walls to section 5
   (iii) Roof and upper floor vertical loading supported by a post and beam frame specifically designed. Such designs are outside the scope of this Standard. Walls to be either in accordance with (b)(i) or (b)(ii) above.

(c) Lintels
   (i) Reinforced masonry or reinforced concrete lintels in accordance with section 8
   (ii) Timber lintels to support light timber frame to section 8 or NZS 3604

(d) Light timber roof and ceiling structure to section 6 and NZS 3604;

(e) Light timber floors to section 6 and NZS 3604;

(f) Arches complying with 9.4.

1.3.3
Systems to resist horizontal loads shall be:

(a) Internal and external walls of earth to section 5;

(b) Bond beams of timber or reinforced concrete to section 7;

(c) Structural diaphragms of timber supporting earth walls, to section 6.

1.4 Interpretation

1.4.1
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.

1.4.2
Clauses prefixed by “C ” and printed in italic type are comments, explanations, summaries of technical the mandatory requirements of compliance within this Standard. The Standard can be complied with if the comment is ignored.

C1.4.2
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 has been adopted as having commentary clauses which have no corresponding mandatory clause.
1.4.3
Cross references to other clauses within this Standard quote the number only.

1.4.4
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.

1.4.5
The full titles of reference documents cited in this Standard are given in the list of related documents immediately preceding the Foreword.

1.4.6
Where the thickness or width is specified for earth walls in this Standard then, unless specifically stated otherwise, the thickness or width shall be the minimum dimensions.

1.4.7
Where any thickness or width is specified for a timber member in this Standard then, unless specifically stated otherwise, that member may have a greater thickness, or a greater width, or both.

1.4.8
Unless specifically stated otherwise cross sectional dimensions of timber given in this Standard shall be the nominal call dimensions.

C1.4.8
The actual dimensions of timber will differ from the call dimensions because of tolerances and according to its condition, e.g. green or dry, sawn, gauged or dressed.

1.5 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.

BAGGING. The practice of rubbing an earth slurry or mortar over the surface of an earth wall with a thick cloth to produce a rendered surface.

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 BEAM. A continuous horizontal structural member in a wall which provides continuity and structural strength.

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.

BOND, STACK. The bond when the units of each course do not overlap the units of the preceding course by the amount specified for overlapping bond. (Not permitted in this Standard).
BOUNDARY JOIST or BOUNDARY MEMBER. A joist running along the outer ends of floor or ceiling joists.

BRACING. Any method employed to provide lateral support to a building.

BRACING CAPACITY. The strength of building elements in resisting horizontal forces. Measured in bracing units (BU).

BRACING DEMAND. The horizontal force imposed on a building by earthquake or wind. Measured in bracing units (BU).

BRACING LINE. A line along or across a building for controlling the distribution of wall bracing elements.

BRACING PANEL. A panel section of earth in a structural wall of solid plan length (with no openings) which gives lateral stability to the building.

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

CINVA BRICK. A pressed earth brick meeting the dimensional and strength requirements of section 6 of NZS 4298.

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

COLUMN. An isolated, reinforced, vertical loadbearing member subjected primarily to compression having a cross section with a depth 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 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 and otherwise move.

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.

DURABLE. Resistant to wear and decay. Durability has a corresponding meaning.

EARTH (for earth building). Natural sub-soil comprised of varying percentages of clay, silt, sand and gravel which is unfired and is free of significant organic matter.

ELASTIC RESPONSE. The response range of a structure where the deformation is in direct proportion to the force applied (i.e. the material, structural component or structure obeys Hooke's law.)
EROSION. The physical and chemical processes by which a material is worn away. It includes the processes of weathering and mechanical wear.

FLOOR LOAD. The basic minimum uniformly distributed live load for floors as specified by NZS 4203.

FRAMING TIMBER. Timber members to which lining, cladding or decking is attached or which are depended upon for supporting the structure or for resisting forces applied to it.

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

GOOD GROUND. Any soil or rock capable of permanently withstanding an ultimate bearing strength of 300 kPa (i.e. an allowable bearing pressure of 100 kPa using a factor of safety 3.0), but excludes:

(a) Potentially compressible ground such as top soil, soft soils such as clay which can be moulded easily in the fingers, and uncompacted loose gravel which contains obvious voids;

(b) Expansive soils being those that have a liquid limit of more than 50 % when tested in accordance with NZS 4402 Test 2.2, and a linear shrinkage of more than 15 % when tested in accordance with NZS 4402 Test 2.6, and

(c) Any ground which could foreseeably experience movement of 25 mm or greater for any reason including one or a combination of: land instability, ground creep, subsidence, seasonal swelling and shrinking, frost heave, changing ground water level, erosion, dissolution of soil in water, and effects of tree roots.

GROUND LEVEL

CLEARED GROUND LEVEL. The ground level after the site has been cleared and any site excavation has been completed but before building footings have been excavated. When topsoil is not stripped off a site, the cleared ground level shall be taken as the bottom of the topsoil layer.

FINISHED GROUND LEVEL. The ground level after all backfilling, landscaping and surface paving having been completed.

NATURAL GROUND LEVEL. The ground level before the site is cleared or excavated.

JOIST. A horizontal framing member to which is fixed floor decking or ceiling linings and which is identified accordingly as a floor joist or ceiling joist.

LINTEL. A horizontal member spanning an opening in a wall.

LOADBEARING. Refers to an element which serves in providing resistance to loads other than those induced by the weight of the element itself.

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.

MUD BRICK. See ADOBE.

PARTIALLY REINFORCED EARTH WALL. An earth wall containing a vertical reinforcing bar at each end of a bracing wall but without any horizontal reinforcement.
PLATE. A horizontal timber member in a wall which supports and distributes the load from floors, walls, ceiling or roof.

PLASTERING. The action of covering an earth wall (for decoration or weather protection) with a coating of earth (with or without stabilizer) and water or sand, cement and water or gypsum plaster.

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

R VALUE. A measure of the ability of a material to retard heat flow.

RAFTER. A framing timber normally parallel to the slope of the roof and providing support for sarking, purlins, or roof covering.

RAMMED EARTH. Damp or moist soil, with or without stabilizer, that is tamped in place 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.

REINFORCED EARTH CONSTRUCTION. Any earth building into which reinforcing is so bedded and bonded that the two materials act together in resisting forces.

REINFORCEMENT. Any form of steel reinforcing rod, bar or mesh that complies with the relevant requirements of NZS 3109, or plastic or other material cited in this Standard capable of imparting tensile strength to the earth building material.

ROOF. That upper part of the building having its upper surface exposed to the outside and at an angle of 60° or less to the horizontal.

The maximum slope of 60° in the definition of roof corresponds to the slope used in NZS 3604 to differentiate between a “roof” and “wall”. Roofs steeper than 45° are outside the scope of this Standard.

HEAVY ROOF means a roof with roofing material (cladding and any sarking) having a mass exceeding 20 kg but not exceeding 60 kg per square metre of roof area (typical examples are concrete tiles, slates and the like).

LIGHT ROOF. A roof with roofing material (cladding and any sarking) having a mass not exceeding 20 kg per square metre of roof area. Typical examples of light roofing are steel, copper, and

SARKING. Sheet material or boards secured to rafters, trusses, or purlins and which may also serve as a ceiling lining or as a roof diaphragm.

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).
SLURRY. A mixture of earth and water that results in a soupy mixture that is easily poured.

SOIL. See earth.

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

SPAN. The clear distance between supports measured along a member.

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 asphalt emulsion.

STABILIZED Poured EARTH. Poured earth which has had stabilizer added, usually cement.

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.

STOREY HEIGHT. The vertical distance measured from the concrete foundation top to the underside of the top plate or bond beam and between the floor level and the underside of the top plate for the second storey.

UNREINFORCED EARTH WALL. An earth wall containing less than the minimum reinforcement required by section 5 for reinforced earth walls.

WALL

WALL BRACING PANEL. A section of wall above the ground level that performs a bracing function.

EXTERNAL WALL. An outer wall of a building.

INTERNAL WALL. A wall other than an external wall.

PARTITION. A light timber wall which is used within the building.

STRUCTURAL WALL. Any wall which because of its position and shape contributes to the rigidity and strength of the building.

WALL PLATE. A horizontal timber member at either the top or bottom of studs in a timber wall frame, or the horizontal timber member on which rafters or roof trusses are supported.

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

2.1 Materials

2.1.1 Earth
Earth materials and construction shall comply with the provisions of NZS 4298 for Standard grade earth construction.

2.1.2 Concrete
All concrete shall satisfy the requirements of NZS 3109 with a minimum specified strength of 17.5 MPa except as otherwise noted in this Standard.

2.1.3 Concrete masonry
Concrete masonry shall comply with the provisions of NZS 4210.

2.1.4 Reinforcement
Steel reinforcing shall comply with NZS 3402. Steel mesh reinforcing shall be hard drawn steel wire to NZS 3421.

2C2.1.4
"Deformed" pattern reinforcing bars and designated "D" followed by the diameter in mm. Plain round reinforcing bars are designated "R" followed by the diameter in mm.

2.1.5 Bolts
At bolted connections washers shall be provided at each timber surface under the bolt head or the nut. Washers for softwoods shall be of the following minimum sizes:

(a) For M12 bolts – 50 mm square x 3 mm or 55 mm round x 3 mm;

(b) For M16 bolts – 65 mm square x 5 mm or 75 mm round x 5 mm.

2.1.6 Corrosion protection
Steel connections and fixings including nails, bolts and nail plates, which are:

(a) Exposed to the weather; or

(b) In contact with earth wall or earth floor material; or

217Mortar
Mortar shall comply with the provisions of NZS 4298.

2.1.8 Timber

2.1.8.1 Timber specified in this Standard for top plates, bond beams and lintels shall be No. 1 Framing Grade to NZS 3631.
2.1.8.2
Timber for lintels not exposed to the weather, top plates and bond beams shall be treated to grade H1 of NZMP 3640, or heart timber from Macarona, Lawson’s or Mexican Cypress, Red Beech Eucalyptus species, or Douglas Fir in accordance with NZS 3602.

2.1.8.3
Timber for lintels exposed to the weather shall be treated to grade H3 of NZS 3640.

2.1.8.4
Timber which is required to be durable and which may be in contact with earth wall construction shall meet the requirements of 2.1.8.2 where it is not exposed to the weather or shall meet the requirements of 2.1.8.3 where it is exposed to weather.

2.2 Methods of construction
This Standard covers the following methods of earth building construction:

(a) Rammed earth;

(b) Adobe;

(c) Pressed brick (including cinva bricks);

<table>
<thead>
<tr>
<th>2.2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C2.2</strong></td>
</tr>
<tr>
<td>Other earth building methods including cob, poured earth, in situ adobe and wattle and daub are not covered by this Standard.</td>
</tr>
</tbody>
</table>

2.3 Earthquake zones
The earthquake zone factor for any locality shall be given by figure 2.1.

2.4 Wind zones

2.4.1
The location (urban, rural, open) of a site is determined by considering the obstructions over which the wind must pass as it approaches that site. At least 500 m of rougher ground is required to affect the wind profile. Sites within this 500 m wide fringe zone shall be considered as if they are in the less rough terrain.

Urban terrain is typical of most residential subdivisions. It is defined as that where the density of obstructions (houses or trees) is not less than 10 per hectare.

Rural terrain is typical farm land, with some trees and shelter belts, cropping and horticulture. Tussock land is also in this category.

Open terrain includes grazed pasture, areas adjacent to beaches and the sea, airfields and other areas with only isolated trees or shelter.

<table>
<thead>
<tr>
<th>C2.4.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>The location classification indicates the drag effect on the wind profile as it passes over different terrains. Urban, rural and open terrains are equivalent respectively to Terrain Categories 3, 2.5 and 2 of Part 5 of NZS 4203.</td>
</tr>
</tbody>
</table>
Figure 2.1 – Earthquake zone factors
2.4.2
The site exposure shall be determined by consideration of the shielding effects of obstructions to wind flow. At least 2 rows of permanent obstructions, similarly sized to the building, in each upwind direction are required for the site to be considered as “sheltered”.

C2.4.2
Typical suburban developments on flat or gently undulating ground, will usually be “sheltered” unless they are adjacent to playing fields or other open spaces, beach fronts, large rivers, motorways, or wind channels greater than 100 m in width, in which case the 2 outer rows of buildings will usually be considered to be “exposed”.
Most houses located on moderate or steep hillside sites should be considered as “exposed”.

2.4.3
The wind zone for each building site shall be determined in accordance with table 2.1.

Table 2.1 – Building wind zones

<table>
<thead>
<tr>
<th>Location</th>
<th>Sheltered</th>
<th>Exposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>L</td>
<td>H</td>
</tr>
<tr>
<td>Rural</td>
<td>M</td>
<td>VH</td>
</tr>
<tr>
<td>Open</td>
<td>H</td>
<td>SD</td>
</tr>
</tbody>
</table>

Key
Symbol Design wind speed at ultimate limit state (m/s)
L 32
M 37
H 44
VH 50
SD >50 specific design required (Outside the scope of this Standard)

2.5 Durability
Compliance with this section is necessary to satisfy the requirements of clause B2 of the New Zealand Building Code.

C2.5
Durability design is summarized in figure 2.3.

2.5.1 General

2.5.1.1 An earth wall will be deemed to comply with the durability performance criteria if, provided that normal surface maintenance has been carried out, the maximum cumulative thickness loss of less than more than 30 mm at any point during the 50 year building life.

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

C2.5.1

Earth walls are particularly susceptible to moisture, whether this is from rising damp, water ingress from the top, driving rain, water splashing, or moisture generated internally in a building. For this reason it is important that any design considers the need to protect earth walls from excessive moisture. Care is to be taken with all weathering details including flashings and eave protection of wall tops. Any applied coatings or surface finishes shall allow the wall to “breathe” to prevent moisture becoming trapped inside an earth wall. To “breathe” in this context means to allow the diffusion of air and water vapour.

A structure is durable if it withstands expected wear and deterioration throughout its intended life without the need for undue maintenance. Deterioration of earth-walls depends on the severity of wind-driven rain, on the orientation of the wall, the height and width of the eaves, on the weather resistance of the wall material, on surface coatings, on the surface finish and on the stability of the material whether naturally occurring or achieved by the addition of stabilizers.

An eaves width of 600 mm is a recommended minimum requirement for earth walls to satisfy the durability requirements of this Standard. More detailed requirements are provided in the following clauses.

2.5.2
The earth wall material erodibility index shall be less than or equal to the site specific building limiting erodibility index.

2.5.3
The earth wall material shall meet the acceptance criteria of the wet/dry appraisal test detailed in Appendix C of NZS 4298.

2.5.4
The earth wall material erodibility index shall be determined by the Erosion Test (Pressure Spray Method) or the Erosion Test (Geelong Method) detailed in Appendices D and E respectively of NZS 4298. In cases where Erodibility Index of 1 is required or where eaves widths are 600 mm or less,
Table 2.2 – Site specific building limiting erodibility indices for different wind zones, wall exposures, eaves heights and widths in areas with up to 2000 mm per year average rainfall

<table>
<thead>
<tr>
<th>Building eaves width (b) (mm)</th>
<th>Limiting erodibility index</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>300</td>
</tr>
<tr>
<td>Wind zone, wall exposure and eaves height (h) (mm)</td>
<td>OS</td>
</tr>
<tr>
<td>Wind zone H and VH</td>
<td>Exposed, 2400</td>
</tr>
<tr>
<td></td>
<td>Exposed, 3000</td>
</tr>
<tr>
<td></td>
<td>Exposed, 3600</td>
</tr>
<tr>
<td></td>
<td>Sheltered, 2400</td>
</tr>
<tr>
<td></td>
<td>Sheltered, 3000</td>
</tr>
<tr>
<td></td>
<td>Sheltered, 3600</td>
</tr>
<tr>
<td>Wind zone M</td>
<td>Exposed, 2400</td>
</tr>
<tr>
<td></td>
<td>Exposed, 3000</td>
</tr>
<tr>
<td></td>
<td>Exposed, 3600</td>
</tr>
<tr>
<td></td>
<td>Sheltered, 2400</td>
</tr>
<tr>
<td></td>
<td>Sheltered, 3000</td>
</tr>
<tr>
<td></td>
<td>Sheltered, 3600</td>
</tr>
<tr>
<td>Wind zone L</td>
<td>Exposed, 2400</td>
</tr>
<tr>
<td></td>
<td>Exposed, 3000</td>
</tr>
<tr>
<td></td>
<td>Exposed, 3600</td>
</tr>
<tr>
<td></td>
<td>Sheltered, 2400</td>
</tr>
<tr>
<td></td>
<td>Sheltered, 3000</td>
</tr>
<tr>
<td></td>
<td>Sheltered, 3600</td>
</tr>
</tbody>
</table>

NOTE –
(1) OS – Outside the scope of this Standard. In these cases specific design following Appendix A of NZS 4297 will be required.

(2) Eaves width, b, and eaves height, h, as defined in figure 2.2.

(3) For eaves widths 600 mm or less, refer to 2.5.4.

C2.5.5
Providing very wide opaque overhangs, without reference to the orientation of walls could lead to very poor thermal (passive solar) performance. Balancing passive solar design and building durability may give rise to a need to substitute a material with a lower erodibility index.

Table 2.2 is concerned with durability. Moisture penetration especially in areas of high exposure to driving rain and small (<900 mm) eaves is dealt with by conforming to other provisions of this Standard and NZS 4298.
2.5.6
The wind zone shall be as given by table 2.1.

2.5.7
The earth wall material erodibility index may be improved by stabilization of the earth wall material by the addition of cement or asphalt emulsion. The improved earth wall material shall be retested using the Spray Erosion Test or the Geelong Drip Test (Appendices D and E of NZS 4298) where appropriate to determine the improved earth wall erodibility index.

2.6 Snow loads
Snow loads shall be determined in accordance with NZS 4203.
Figure 2.3 – Durability design

1.2(j) Rainfall greater than 2000 mm?

Yes

Specific design to NZS 4297

No

Table 2.1

Site exposure?

Wind zone = SD?

Yes

No

Table 2.2

Determine required erodibility index

Wall height and eaves width?

Table 2.2

Outside scope? (OS)

No

Yes

Wind zone

VH, H, M or L?

NZS 4298 App. C

Wet/dry appraisal test passed?

Pass

Is eaves 600 mm or less?

Yes

Test erodibility index

Pass

Fail

NZS 4298 App. D or E

Test erodibility index

No

Yes

NZS 4298 App. D

Test erodibility index

Fail

Pass

Is required erodibility index equal to or greater than test result?

Yes

Proceed

No

Use different material

Re-test
2.7 Concrete durability

2.7.1
Minimum concrete cover to steel reinforcement shall be 50 mm.

2.7.2
Minimum specified concrete strength shall be:

(a) 17.5 MPa for unreinforced concrete, for concrete not exposed to weather or for concrete exposed to the weather within a low concrete reinforcing corrosion risk area as defined in 2.7.3;

(b) 20 MPa for concrete exposed to weather and from 500 m from the Mean High Water Springs mark to the boundary of a low concrete reinforcing corrosion risk area as defined in 2.7.3;

(c) 25 MPa for concrete exposed to weather and within 500 m of the Mean High Water Springs mark.

2.7.3
Low concrete reinforcing corrosion risk areas are defined as:

(a) In the North Island:
   (i) Near the West Coast from Cape Reinga to Cape Terawhiti, except Taranaki Region, Manawatu District and Palmerston North City, areas further than 30 km from the Mean High Water Springs mark
   (ii) In Taranaki Region, Manawatu District and Palmerston North City, areas further than 40 km from the Mean High Water Springs mark
   (iii) Elsewhere in the North Island, areas further than 20 km from the Mean High Water Springs mark.

(b) In the South Island:
   (i) Near the West Coast from Cape Farewell to Puysgur Point, areas further than 40 km from the Mean High Water Springs mark
   (ii) Elsewhere in the South Island, areas further than 20 km from the Mean High Water Springs mark.

(c) No areas within offshore islands are included.

Some of the areas described will be outside the scope of this Standard by virtue of rainfall or wind exposure.

2.8 Materials testing
Standard grade earth construction as defined in NZS 4298 shall be used for earth buildings deemed to comply with this Standard. Test procedures and results required are detailed in the Appendices to NZS 4298.
2.9 Thermal insulation

2.9.1 For housing, as defined in NZS 4218, the thermal insulation requirements of NZS 4218 are satisfied by earth walled buildings having a minimum wall thickness of 280 mm provided the conditions of table 2.3 are met.

Table 2.3 – Earth wall construction for thermal performance

<table>
<thead>
<tr>
<th>Building thermal envelope component</th>
<th>Climate zones 1 &amp; 2</th>
<th>Climate zone 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor</td>
<td>Minimum $R = 1.3 , m^2 \cdot °C/W$</td>
<td>Minimum $R = 1.3 , m^2 \cdot °C/W$</td>
</tr>
<tr>
<td>Roof</td>
<td>Minimum $R = 2.3 , m^2 \cdot °C/W$</td>
<td>Minimum $R = 2.3 , m^2 \cdot °C/W$</td>
</tr>
<tr>
<td>Glazing area maximum</td>
<td>30 % of wall area</td>
<td>30 % of wall area</td>
</tr>
<tr>
<td>Glazing type</td>
<td>Single or double</td>
<td>Double</td>
</tr>
</tbody>
</table>

NOTE –

(1) Climate zone boundaries are given by 2.9.2.

(2) Temporary floor coverings such as carpets or floor coverings shall not be included in the floor $R$-value.

(3) The floor $R$-value is met by:
   (a) Concrete slab-on-ground in accordance with NZS 3604; or
   (b) Suspended timber floors in accordance with NZS 3604 with drooped foil in accordance with NZS 4222 with a continuous enclosed perimeter wall which has from 3500 to 7000 mm $^2$ per m$^2$ of sub-floor ventilation; or
   (c) Earth floors constructed in accordance with Appendix M of NZS 4298.

(4) Double glazing shall have a minimum $R$-value of 0.33 $m^2 \cdot °C/W$ in accordance with NZS 4218.

C2.9.1 Glazing above 30 % of wall area may lead to solar overheating and excessive heat loss. Use of the Calculation Method or Modelling Method of NZS 4218 is advised for over 30 % glazing.

$R = 3.0$ for roof insulation is recognized as a minimum desirable value for passive solar design.

2.9.2 Zones 1 and 2 comprise the whole of the North Island excluding Taupo District, Ruapehu District and the northern part of the Rangitikei District.

Zone 3 comprises the remainder of the country i.e. Taupo District, Ruapehu District, northern part of the Rangitikei District, South Island and all other islands not in Zones 1 and 2.

C2.9.2 The climate zone boundaries are based on climatic data taking into consideration territorial authority boundaries, providing for 3 zones.

The climate zones follow NZS 4218 and a map may be found in that Standard.
2.10 Protection of earth walls from external moisture

2.10.1
Suitable protection from exterior moisture to all earth walls shall be provided by minimum eave and verge widths to all earth walls in accordance with table 2.4.

Table 2.4 – Exterior moisture protection for earth walls

<table>
<thead>
<tr>
<th>Building wind zone (from table 2.1)</th>
<th>Ratio of eaves height to eaves width, ( h:b ) (see figure 2.2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>4:1</td>
</tr>
<tr>
<td>M</td>
<td>8:3</td>
</tr>
<tr>
<td>H</td>
<td>3:2 (see clause 2.10.2)</td>
</tr>
<tr>
<td>VH</td>
<td>1:1</td>
</tr>
</tbody>
</table>

C2.10.1
Walls that comply with table 2.2 may still be susceptible to problems from penetration of external moisture over time and these provisions ensure against this.

The ratios in table 2.4 are minimums and greater eaves widths may be specified. Lesser eaves widths combined with other weather protection measures such as fences, pergolas or other permanent landscaping features may also be possible in some cases by using specific design but this is outside the scope of this Standard.

NZS 3604 provides for eaves overhangs of up to 750 mm and cantilevered overhangs greater than this will require specific engineering design. Verandahs may be provided in accordance with NZS 3604 where an eaves width greater than 750 mm is required.

2.10.2
In high wind zones the ratio may be reduced to 2:1 for earth walls not stabilized with cement or lime and that have open exposure and face northerly between north east and north west.

C2.10.2
In the High Wind Zone, the improved waterproofing properties of clay surfaces, which are free to swell to form a waterproof layer, are recognized. When these materials get wet they have superior waterproofing properties compared to the more porous matrices formed by cement and lime.
3 SITE REQUIREMENTS

C3
The site requirements of this Standard are concerned with drainage and soil conditions under or adjacent to the building. Compliance with these requirements does not necessarily mean that the site is suitable for the building in terms of subdivisional and planning legislation.

3.1 Soil bearing capacity and site profile requirements

C3.1
If a site does not comply with 3.1, then it will be necessary for the footings to be the subject of specific design. However, this Standard may still apply to the rest of the building provided it complies with 1.2 and the footings are designed to suit.

3.1.1 Location of footings
The footing provisions of this Standard shall apply only for building sites such that:

(a) The foundation of the building shall be supported by “good ground” as defined in 1.5;

(b) Any footing for a building erected at the top of a slope, shall be no nearer any point on the slope than shown in figure 3.1(a);

(c) Where the ground level rises above floor level adjacent to earth wall, there shall be a minimum of 1000 mm between the toe of a slope and the earth wall. A lined drain with a longitudinal fall of at least 1:150 and paving shall be provided where the toe of the slope is less than 1200 mm from the wall as shown in figure 3.1(b);

Figure 3.1 – Relationship of foundation to sloping ground surface
(d) Any ground within 1.5 m horizontal distance from any footing and more than 300 mm above the cleared ground level at the footing shall be natural undisturbed ground.

C3.1.1
(c) Clause 3.1.1(c) is intended to ensure that footing loadings do not cause adjacent slopes to become unstable.

(d) Moderate depths of earth fill over a large area adjacent to building footings can cause the soil to consolidate at greater depths than are influenced by the footings specified in this Standard. Such consolidation can cause differential settlement of the building footings and thus damage the building. Typically, earth fills are placed adjacent to footings for the construction of stairs, terraces, landscaping, and built up ground under concrete floor slabs.

3.1.2 Soil bearing capacity
The test and the investigations required by this clause shall be performed by people with appropriate skills to the approval of the territorial authority.

3.1.2.1 The soil supporting the footings shall be assumed to be good ground if:

(a) Adjacent established buildings of a similar type supported on footings similar to those required by this Standard and on similar soils show no signs of unsatisfactory behaviour attributable to soil conditions; or

(b) Dynamic cone penetrometer (also known as Scala Penetrometer) tests in accordance with NZS 3604 have been performed establishing that the supporting soils are good ground; and

(c) Provided all of the conditions of 3.1.2.2 are met.

C3.1.2.1 Good ground may also be verified by a subsoil investigation but this is outside the scope of this Standard.

Tests in accordance with NZS 3604 offer a comparatively simple method for establishing whether or not an ultimate bearing strength of 300 kPa may be assumed.

3.1.2.2 Site and soil conditions required to be met are:

(a) Reasonable enquiry, the project information memorandum (PIM) and site observation show no evidence of buried services and none are revealed by excavation for footings; and

(c) Reasonable enquiry shows no evidence of earth fill on the building site and no fill material is revealed by excavation for footings; provided that this shall not apply where a certificate of suitability of earth fill for residential development has been issued in terms of NZS 4431 in respect of the building site and any special limitations noted on that certificate are complied with; and

(d) Excavation for footings does not reveal buried organic topsoil, soft peat, soft clay or loose sand (see 3.2.1).
3.2  Soil types

3.2.1  Soft peat and soft clay
For the purposes of 3.1.2(e) peat or clay soil shall be regarded as soft if a natural chunk of the soil (not remoulded material or loose shavings) can be easily moulded in the fingers. (Soil that exudes between the fingers when squeezed in a fist shall be regarded as very soft.)

3.2.2  Loose sand
For the purpose of 3.1.2(e) loose sand shall be that sand which when in a dry state has a natural angle of repose when poured into a heap of less than 3 horizontal to 2 vertical (33° to the horizontal).

C3.2.2
The design bearing capacity of a footing bearing on sand depends on the width of the footing and its depth below the surface, the density of the sand and, in particular, bearing capacity factors which are dependent on the internal angle of friction of the sand. The natural angle or repose of a loose sand heap gives a reasonable indication of the internal angle of friction of a sand.

3.3  Bearing

3.3.1
All footings shall bear upon solid bottom in undisturbed material or upon fill which complies with 3.1.2(d). Such material is referred to in this Standard as firm bearing.

3.3.2
The minimum depths of footings below the cleared ground level shall be:

(a) 150 mm in firm weathered rock;

(b) 300 mm in other materials, except for expansive clays, subject to any special limitations noted on a certificate of suitability issued in terms of NZS 4431 in respect of the building site (see 3.1.2(d));

(c) Where expansive clays occur the foundations shall be specifically designed. Such design is outside the scope of this standard.

C3.3.2
“Cleared ground level” is used as the depth datum because this level is not usually altered by future landscaping, thus retaining the lateral support of the building.

3.4  Site drainage and flood avoidance
The site shall be located or built up such that under severe flood conditions (200 year event) water does not rise above the top of the concrete, stone or other such durable foundation layer. Determination of these levels is outside the scope of this Standard.

C3.4
Flood waters can destroy adobe or lightly stabilized earth wall materials that are inundated for more than short periods. This could lead to overall structural collapse. More care is needed in siting earth wall buildings than for conventional construction.

Some situations that require specific consideration are:

(a) Height above river or stream flood level;

(b) Flood paths on sloping ground;
(c) Adequate drainage to prevent overland flow accumulation;

(d) Height above maximum storm wave upwash combined with maximum likely water levels on lakes or sea.

3.5 Site preparation

3.5.1
Before a building is erected on any site all rubbish, noxious matter, and organic matter shall be removed from the area to be covered by the building.

In suspended floor construction, (but not in slab-on-ground construction) firm turf and close-cut grass may remain provided that for the purposes of complying with 3.3.2, cleared ground level shall be taken as the underside of soil containing organic matter.

3.5.2
Any subsoil drains severed during the excavation process shall be reinstated or diverted and the building area shall be permanently drained to ensure freedom from surface water in the subfloor space.

C3.5.2
Footings should be backfilled and compacted up to cleared ground level.

4 FOOTINGS

4.1 General

4.1.1
Every earth wall, whether loadbearing or non-loadbearing, shall be supported by a continuously reinforced concrete footing of the dimensions and reinforcement given in this section.

4.1.2
The footing shall be formed symmetrically about the centre line of the wall.

C4.1.2
If 4.1.2 cannot be satisfied because a wall is to be built up to a boundary or for any other reason, then it will be necessary for both the footing and the wall to be the subject of specific design. Such design is outside the scope of this Standard.

4.1.3
The footing shall have all soil bearing surfaces horizontal but may be stepped to accommodate variations defined in 3.1.1.

4.2 Width of footing

4.2.1
The width of the footing shall not be less than 280 mm nor the width of the earth wall construction whichever is the greater.

4.2.2
The width of the footing shall not exceed 450 mm.
4.3 Depth of footing
The footing shall extend to at least the depths below cleared ground level and be on firm bearing as defined in 3.3, refer to figure 4.1.

4.4 Height of footing

4.4.1
The top of the footing at the underside of the earth wall shall be:

(a) A minimum of 225 mm above the finished exterior ground level;

(b) A minimum of 50 mm above the interior floor level during construction before weatherproofing of the roof;

(c) A maximum of 600 mm above the cleared ground level;

(d) A minimum of 150 mm above permanent paving.

Refer to figure 4.1.

C4.4.1
Footing walls exceeding 600 mm height above cleared ground level will require specific design as these are outside the limitations defined in 1.2.

The clearance above interior floor level of (b) is to avoid soaking of wall base by ponded water during construction.

4.4.2
The walls in wet areas of buildings shall be provided with a concrete footing which is a minimum of 50 mm above floor level.

C4.4.2
4.5 Reinforcement of footings

4.5.1 Reinforcement of footings where earthquake zone factor \( \leq 0.6 \)

4.5.1.1 Longitudinal reinforcement shall consist of one of:

(a) 4/D12 or 2/D16 bars for footings not exceeding 350 mm wide;

(b) 4/D16 bars for footings exceeding 350 mm wide;

4.5.1.3 Reinforcement at intersections shall be tied together with D12 L bars top and bottom and lapped 40 bar diameters as shown in figure 4.4.

Refer figures 4.2 to 4.7.
4.5.2 Reinforcement of footings where earthquake zone factor > 0.6

4.5.2.1 Longitudinal reinforcement shall consist of:

(a) 3/D16 for foundation types E and G with fired brick facing, refer to figures 4.5 and 4.7;

(b) 4/D16 bars for all other footings.

Refer to figure 4.3.
4.5.2.2
Footing reinforcement shall be tied with R10 stirrups at 400 mm centres.

Reinforcement at footing intersections shall be tied together with D16 L bars top and bottom and lapped 40 bar diameters as shown in figure 4.4.

Figure 4.4 – Reinforcement at footing or bond beam intersections

4.6 Cover to reinforcement
The cover to reinforcement in the footing shall be:

4.7 Vertical wall starter reinforcement

4.7.1 Vertical wall starter reinforcement of the same diameter, type, spacing and location as the wall vertical reinforcement shall be provided in every footing for reinforced and partially reinforced earth walls so as to penetrate the wall to a distance of not less than 600 mm.
4.7.2
Vertical wall starter reinforcement shall be tied and anchored by the provision of at least one 90° bend around a tie bar the same size or larger than the wall starter contained in the bottom of the footing followed by a horizontal leg of 200 mm minimum.

4.8 Concrete slab-on-ground floors

4.8.1 General
Concrete floor slabs, where provided shall comply with the requirements of the following clauses.

4.8.2
The finished concrete floor level shall be a minimum of 175 mm above the adjoining finished exterior ground level or 100 mm above the finished level of adjoining permanent paving. Refer to figure 4.1.

C4.8.2
This provision is to limit splash back and avoid water ponding or damp soil build up against the base of a wall.

4.8.3 Bearing

4.8.3.1
Clause 4.3 (minimum depth of footings below cleared ground level) shall apply to the footing walls but not to the ground slab itself. For external walls, the depth shall be measured from the cleared ground level outside the footing wall and not from the cleared ground level beneath the ground slab. For internal walls the depth shall be measured from the cleared ground level beneath the floor slab. See figure 4.1.

4.8.3.2
The cleared ground level beneath the slab shall be such that:

(a) The granular fill material required by 4.8.4 shall be placed either on solid bottom or on firm fill which complies with 3.1.2(d);

(b) The thickness of granular fill shall be not less than 75 mm nor greater than 600 mm.

4.8.4 Granular fill
The granular base shall comply with the following requirements:

(a) It is placed and compacted in layers not exceeding 150 mm thick before compaction;

(b) Granular fill material shall be composed of rounded gravel, crushed rock and:

(i) Not more than 5 % shall pass a 2.2 mm sieve;

(A) 19 mm sieve for any fill thickness; or

(B) 37.5 mm sieve for a fill thickness exceeding 100 mm.

4.8.5 Vapour barriers
The vapour barrier under the concrete slab shall comply with the requirements of NZS 3604.

4.8.6 Thickness and reinforcement
The thickness and reinforcement of concrete slabs shall comply with the requirements of NZS 3604.
4.8.7 Support of loadbearing timber internal walls
The support of loadbearing timber wall shall comply with the requirements of NZS 3604.

4.9 Damp proof course

4.9.1
A damp proof course shall be provided on the top of the footing at the underside of the earth wall.

The top of the concrete footing shall be roughened to 5 mm amplitude prior to the application of the damp proof course.

The damp proof course shall comprise 2 coats of bituminous paint for the full width of the earth wall or material which complies with AS/NZS 2904.

4.10 Splashback course

C4.10
A splashback back course of fired brick or poured concrete may be provided between the top of the concrete footing and underside of the earth wall to reduce the risk of erosion to the base of the wall particularly in exposed locations with driving rain or to protect the base of the wall during construction.

4.11 Footing construction details

4.11.1
Footing construction details for earth brick construction in accordance with this Standard shall be as shown on figures 4.1 to 4.7.

C4.11

Figure 4.5 – Alternative strip footing type E with fired brick facing
Figure 4.6 – Footing type F with concrete floor slab

Figure 4.7 – Footing type G with concrete floor slab and fired brick facing

NOTE -
(1) All other dimensions and details as per figure 4.1.
(2) Wall starter bars not shown.
5 WALLS

5.1 General

5.1.1 The wall system of each storey shall consist of:

(a) A wall system of earth with or without loadbearing light timber framing walls to resist vertical loads complying with 5.2, combined with

(b) A wall system of earth to resist horizontal loads complying with 5.3, combined with

(c) Any other wall which is non-loadbearing shall be of light timber framing and shall not be taken into account for the purposes of 5.2 and 5.3.

5.1.2 Cinva brick walls shall be reinforced in all zones.

Where the earthquake zone factor, \( Z \leq 0.6 \), earth walls may be either reinforced, partially reinforced or unreinforced. Where reinforced, such walls shall be in accordance with 5.5 and 5.8. Where unreinforced, such walls shall be in accordance with 5.6. Where partially reinforced, such walls shall be in accordance with 5.7.

5.1.3 The thickness of earth walls shall be a minimum of 280 mm except for cinva brick walls which shall conform with section 11 of this Standard.
5.1.4
The maximum thickness of earth walls for earth buildings complying with this Standard shall be 350 mm exclusive of any surface finishes including plaster.

C5.1.4
Earth buildings with earth walls thicker than provided for in 5.1.4 are outside the scope of this Standard and will require specific design.

5.1.5
Structural diaphragms complying with section 6 or bond beams complying with section 7 shall be provided at the top of all earth walls and at first floor and ceiling levels.

C5.1.5
Generally structural diaphragms are recommended in preference to bond beams.

5.1.6
Openings on external walls shall be located a minimum of 900 mm from the outside edge of an external corner.

5.1.7
Earth wall panels between openings shall have a minimum length of 600 mm.

5.2  Wall systems to resist vertical loads

5.2.1
The wall system to resist vertical loads shall be such that all roof framing members and all floor framing members shall be directly supported by any of the following or any combination of them:

(a) Structural walls constructed of earth;

(b) Loadbearing timber framing in accordance with NZS 3604 which may be supported on earth walls;

(c) Timber lintels in accordance with NZS 3604 which may be supported on earth walls;

(d) Reinforced concrete or timber lintels complying with section 8;

(e) Another roof or floor framing member;

(f) Reinforced concrete footing walls and footings.

5.2.2
No earth walls within the scope of this Standard shall be supported on a timber structure, except for timber lintels in accordance with section 8.

5.2.3
Lintels shall be fixed to earth walls in accordance with section 8.

5.3  Earth wall systems to resist horizontal loads

5.3.1  General
All earth buildings shall be braced by earth bracing walls in each of the 2 principal directions of the building, at 90° to each other, to resist horizontal wind and earthquake loads.

C5.3.1
Figure 5.1 is a chart summarizing the method for determining the bracing demand for a building.
Figure 5.2 is a chart summarizing the method for determining the bracing capacity of walls.
Figure 5.1 – Determination of bracing demand
For earth buildings within the scope of this standard, the requirements for walls to be able to resist wind loads will in all cases be met or exceeded by the provisions required to resist earthquake loads.

The centrelines of parallel bracing lines shall be not more than 6 m apart. Refer to figure 5.3.

The earth walls of a building shall be subdivided into panels of various lengths as determined by 5.3.6.

Bracing walls shall be those full height panels with a minimum height of 1.8 m, a minimum length of 1.2 m for walls up to 2.4 m high, a minimum length of 1.5 m for walls up to 3.0 m high and a minimum length of 1.8 m for walls up to 3.3 m high and with no openings within the panel between the footing and top plate or bond beam. For the effective height of raking or gable end walls refer to 5.3.12.

The length of a bracing wall shall be the horizontal length along the wall between wall ends, openings, corners or control joints.
5.3.7 Subject to the requirements of 5.4, 5.5 and 5.6, wall bracing elements shall as far as is practicable be located at the corners of external walls and evenly throughout the buildings.

C5.3.7 The horizontal torsional resistance of buildings to resist earthquake and wind forces, are best

in one outside wall is not less than 50% of the total of the bracing capacity in the opposite, parallel outside wall.

5.3.9 Bracing walls may be a maximum of 1 m either side of the bracing wall support line and contribute to the total bracing capacity for that support line.

C5.3.9 The bracing line chosen is to represent the combined line of action of all walls considered to act on that line and bracing walls may be a maximum of 1 m either side of the bracing wall support line.
5.3.10 Where bracing walls are at the following angles to the bracing wall support line they may contribute to the total bracing capacity of that support line as follows:

(a) 30° to one direction and 60° in the other direction, 0.87 and 0.5 times the bracing capacity of the bracing wall;

(b) 45° to both directions, 0.7 times the bracing capacity of the bracing wall;

(c) The factors for other angles shall be obtained by specific design and is outside the scope of this Standard.

5.3.11 A bracing line shall consist either of all reinforced panels or all unreinforced panels and partially reinforced.

5.3.12 The effective height of a raking wall or gable end wall shall be taken as its average height.

5.3.13 Top storey timber wall bracing shall be as determined by NZS 3604.

5.3.14 Reinforced rammed earth walls may be designed and built without horizontal reinforcing by spacing vertical D12 steel bars as per table 5.10, and by following all other relevant sections of this standard.

5.4 Bracing demand for reinforced earth walls where earthquake zone factor > 0.6

5.4.1 The bracing demand for various building types, building lengths, and bracing wall support line spacings shall be as shown in the following tables:

(a) Table 5.1 for single storey earth walls and light roof;

(b) Table 5.2 for single storey earth walls and heavy roof;

(c) Table 5.3 for lower storey earth walls and timber part second storey and light roof;

(d) Table 5.4 for lower storey earth walls and timber second storey and light roof.

C5.4.1
For reinforced earth walls with limited ductility 20 bracing units are equivalent to 1 kN lateral force at the ultimate limit state at the top plate level with assumed construction of ground floor earth walls, or timber second storey and light roof.

For walls nominally 300 mm thick the values from tables 5.1 to 5.4 for 280 mm walls will apply.
Table 5.1 – Bracing demand for bracing support lines for
- single storey earth walls
- light roof, and
- earthquake zone factor > 0.6

<table>
<thead>
<tr>
<th>Wall thickness and wall or storey height</th>
<th>Building length in direction of bracing walls (m)</th>
<th>Bracing demand (Bracing Units)</th>
<th>Exterior walls</th>
<th>Interior walls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Support line spacing (m)</td>
<td>Support line spacing (m)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.0</td>
<td>4.5</td>
<td>6.0</td>
</tr>
<tr>
<td>280 thick walls 2400 high</td>
<td>6</td>
<td>310</td>
<td>370</td>
<td>430</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>465</td>
<td>555</td>
<td>645</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>620</td>
<td>740</td>
<td>860</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>775</td>
<td>925</td>
<td>1075</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>1086</td>
<td>1295</td>
<td>1505</td>
</tr>
<tr>
<td>280 thick walls 2750 high</td>
<td>6</td>
<td>355</td>
<td>424</td>
<td>493</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>533</td>
<td>636</td>
<td>739</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>711</td>
<td>848</td>
<td>985</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>888</td>
<td>1060</td>
<td>1232</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>1243</td>
<td>1484</td>
<td>1724</td>
</tr>
<tr>
<td>350 thick walls 2400 high</td>
<td>6</td>
<td>388</td>
<td>463</td>
<td>537</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>581</td>
<td>694</td>
<td>806</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>775</td>
<td>925</td>
<td>1075</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>969</td>
<td>1156</td>
<td>1344</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>1357</td>
<td>1619</td>
<td>1881</td>
</tr>
<tr>
<td>350 thick walls</td>
<td>6</td>
<td>444</td>
<td>530</td>
<td>616</td>
</tr>
</tbody>
</table>
Table 5.2 – Bracing demand for bracing support lines for
- single storey earth walls
- heavy roof,
- and earthquake zone factor > 0.6

<table>
<thead>
<tr>
<th>Wall thickness and wall or storey height</th>
<th>Building length in direction of bracing walls (m)</th>
<th>Bracing demand (Bracing Units)</th>
<th>Support line spacing (m)</th>
<th>Support line spacing (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Exterior walls</td>
<td>3.0 4.5 6.0</td>
<td>Interior walls</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Support line spacing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.0 4.5 6.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>280 thick walls 2400 high</td>
<td>6</td>
<td>330 400 470</td>
<td>460 599 739</td>
<td>300 430 570</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>495 600 705</td>
<td>690 899 1109</td>
<td>500 700 900</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>660 800 939</td>
<td>919 1199 1478</td>
<td>700 920 1200</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>825 1000 1174</td>
<td>1149 1499 1848</td>
<td>900 1220 1620</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>1155 1399 1644</td>
<td>1609 2099 2587</td>
<td>1200 1680 2160</td>
</tr>
<tr>
<td>280 thick walls 2750 high</td>
<td>6</td>
<td>378 458 538</td>
<td>527 687 847</td>
<td>325 455 615</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>567 687 807</td>
<td>790 1030 1270</td>
<td>500 680 860</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>756 916 1076</td>
<td>1053 1373 1693</td>
<td>750 1000 1300</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>945 1145 1345</td>
<td>1316 1717 2117</td>
<td>900 1200 1560</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>1323 1603 1883</td>
<td>1843 2403 2963</td>
<td>1200 1600 2080</td>
</tr>
<tr>
<td>350 thick walls 2400 high</td>
<td>6</td>
<td>412 500 587</td>
<td>574 749 924</td>
<td>375 525 725</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>619 749 880</td>
<td>862 1124 1386</td>
<td>500 680 860</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>825 999 1174</td>
<td>1149 1498 1847</td>
<td>700 920 1200</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>1031 1249 1467</td>
<td>1436 1873 2309</td>
<td>900 1220 1620</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>1443 1749 2054</td>
<td>2011 2622 3233</td>
<td>1200 1680 2160</td>
</tr>
<tr>
<td>350 thick walls 2750 high</td>
<td>6</td>
<td>472 572 672</td>
<td>658 858 1058</td>
<td>375 525 725</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>708 859 1009</td>
<td>987 1287 1587</td>
<td>500 680 860</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>945 1145 1345</td>
<td>1316 1716 2116</td>
<td>700 920 1200</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>1181 1431 1681</td>
<td>1645 2145 2645</td>
<td>900 1220 1620</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>1653 2003 2353</td>
<td>2303 3003 3703</td>
<td>1200 1680 2160</td>
</tr>
</tbody>
</table>
Table 5.3 – Bracing demand for bracing support lines for
• single storey earth walls
• timber part storey
• light roof, and
• earthquake zone factor > 0.6

<table>
<thead>
<tr>
<th>Wall thickness and wall or storey height</th>
<th>Building length in direction of bracing walls (m)</th>
<th>Bracing demand (Bracing Units)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Exterior walls</td>
<td>Interior walls</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Support line spacing (m)</td>
<td>Support line spacing (m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.0</td>
<td>4.5</td>
<td>6.0</td>
<td>3.0</td>
</tr>
<tr>
<td>280 thick walls</td>
<td>6</td>
<td>351</td>
<td>428</td>
<td>504</td>
<td>503</td>
</tr>
<tr>
<td>2400 high</td>
<td>9</td>
<td>527</td>
<td>642</td>
<td>757</td>
<td>754</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>703</td>
<td>856</td>
<td>1009</td>
<td>1005</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>879</td>
<td>1070</td>
<td>1261</td>
<td>1257</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>1230</td>
<td>1498</td>
<td>1765</td>
<td>1759</td>
</tr>
<tr>
<td>280 thick walls</td>
<td>6</td>
<td>403</td>
<td>490</td>
<td>578</td>
<td>576</td>
</tr>
<tr>
<td>2750 high</td>
<td>9</td>
<td>604</td>
<td>735</td>
<td>867</td>
<td>864</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>805</td>
<td>980</td>
<td>1156</td>
<td>1151</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>1006</td>
<td>1225</td>
<td>1444</td>
<td>1439</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>1409</td>
<td>1716</td>
<td>2022</td>
<td>2015</td>
</tr>
<tr>
<td>350 thick walls</td>
<td>6</td>
<td>439</td>
<td>535</td>
<td>630</td>
<td>628</td>
</tr>
<tr>
<td>2400 high</td>
<td>9</td>
<td>659</td>
<td>802</td>
<td>945</td>
<td>942</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>878</td>
<td>1069</td>
<td>1261</td>
<td>1256</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>1098</td>
<td>1337</td>
<td>1576</td>
<td>1570</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>1537</td>
<td>1872</td>
<td>2206</td>
<td>2198</td>
</tr>
<tr>
<td>350 thick walls</td>
<td>6</td>
<td>503</td>
<td>613</td>
<td>722</td>
<td>719</td>
</tr>
<tr>
<td>2750 high</td>
<td>9</td>
<td>755</td>
<td>919</td>
<td>1083</td>
<td>1079</td>
</tr>
</tbody>
</table>
Table 5.4 – Bracing demand for bracing support lines for
- single storey earth walls
- timber second storey
- light roof, and
- earthquake zone factor > 0.6

<table>
<thead>
<tr>
<th>Wall thickness and wall or storey height</th>
<th>Building length in direction of bracing walls (m)</th>
<th>Bracing demand (Bracing Units)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Exterior walls</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Support line spacing (m)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.0</td>
</tr>
<tr>
<td>280 thick walls 2400 high</td>
<td>6</td>
<td>393</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>589</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>785</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>982</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>1375</td>
</tr>
<tr>
<td>280 thick walls 2750 high</td>
<td>6</td>
<td>450</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>675</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>900</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>1125</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>1574</td>
</tr>
<tr>
<td>350 thick walls 2400 high</td>
<td>6</td>
<td>491</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>736</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>982</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>1227</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>1718</td>
</tr>
<tr>
<td>350 thick walls 2750 high</td>
<td>6</td>
<td>562</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>843</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>1124</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>1405</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>1968</td>
</tr>
</tbody>
</table>
5.4.2 Buildings without earth gable end walls
The total bracing capacity of the building in each direction shall comply with the minimum number per square metre shown in table 5.5 for buildings without earth gable walls. The total bracing demand at any support line as shown in tables 5.1 to 5.4 shall be reduced by up to 30% provided the total bracing capacity of the building in each direction complies with the minimum number per m² shown in table 5.5 for buildings without earth gable walls.

C5.4.2
The wall bracing capacity is able to be reduced by up to 30% allowing for the conservative assumption of walls at 3 m spacings in the calculation of wall bracing demand for each support line.

5.4.3 Buildings with earth gable end walls
The total bracing capacity of the building in each direction shall comply with the minimum number per square metre shown in table 5.5 plus the total face area of earth gable walls above the nominal building height multiplied by 50 for buildings with earth gable walls. The bracing demand at any support line as shown in tables 5.1 to 5.4 shall be reduced by up to 30% provided the total bracing capacity of the building in each direction complies with the minimum number per m² shown in table 5.5 plus the total face area of earth gable walls above the nominal building height multiplied by 50 for buildings with earth gable walls.

Table 5.5 – Minimum bracing demand per square metre for earthquake zone factor > 0.6

<table>
<thead>
<tr>
<th>Support line spacing (m)</th>
<th>Earth wall thickness (mm)</th>
<th>Bracing units required per m² of external floor plan area of building</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2400 mm wall or storey height</td>
<td>2750 mm wall or storey height</td>
</tr>
<tr>
<td>Single storey earth walls and light roof</td>
<td>280</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>350</td>
<td>25</td>
</tr>
<tr>
<td>Single storey earth</td>
<td>280</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>350</td>
<td>48</td>
</tr>
<tr>
<td>Lower storey 280</td>
<td>350</td>
<td>48</td>
</tr>
</tbody>
</table>

5.4.4
The bracing capacity of reinforced earth bracing walls shall be as shown in table 5.6. Refer to 5.3.12 for the height of raking or gable end walls.
Table 5.6 – Bracing capacity of reinforced earth walls

<table>
<thead>
<tr>
<th>Wall length (L) (m)</th>
<th>Wall heights (m)</th>
<th>2.4</th>
<th>2.7</th>
<th>3.0</th>
<th>3.3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bracing units provided</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2</td>
<td>262</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>1.5</td>
<td>347</td>
<td>309</td>
<td>278</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>1.8</td>
<td>432</td>
<td>384</td>
<td>346</td>
<td>314</td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>517</td>
<td>459</td>
<td>413</td>
<td>376</td>
<td></td>
</tr>
<tr>
<td>2.4</td>
<td>601</td>
<td>535</td>
<td>481</td>
<td>437</td>
<td></td>
</tr>
<tr>
<td>2.7</td>
<td>686</td>
<td>610</td>
<td>549</td>
<td>499</td>
<td></td>
</tr>
<tr>
<td>3.0</td>
<td>771</td>
<td>685</td>
<td>617</td>
<td>561</td>
<td></td>
</tr>
<tr>
<td>&gt;3.0</td>
<td>130+210xL</td>
<td>60+205xL</td>
<td>40+190xL</td>
<td>50+170xL</td>
<td></td>
</tr>
</tbody>
</table>

NOTE – Maximum wall heights are limited by 1.2.

5.5 Bracing demand for reinforced earth walls where earthquake zone factor ≤ 0.6

5.5.1
The bracing demand for various building types, building lengths and bracing wall support line spacings shall be 50 % of those shown in tables 5.1 to 5.4.

5.5.2
The total bracing capacity of the building in each direction shall comply with the minimum number per square metre in accordance with 5.4.2 and 5.4.3 divided by 2. The bracing demand at any support line shall be reduced by up to 30 % provided the total bracing capacity of the building in each direction complies with the minimum number of bracing units per square metre in accordance with 5.4.2 and 5.4.3 divided by 2.

5.5.3
The bracing capacity of reinforced earth bracing walls shall be as shown in table 5.6.

5.6 Bracing demand for unreinforced earth walls where earthquake zone factor ≤ 0.6

5.6.1
The bracing demand for various building types, building lengths and bracing wall support line spacings shall be 50 % of those shown in tables 5.1 to 5.4.

5.6.2
The total bracing capacity of the building in each direction shall comply with the minimum number per square metre in accordance with 5.4.2 and 5.4.3 divided by 2. The bracing demand at any support line shall be reduced by up to 30 % provided the total bracing capacity of the building in each direction complies with the minimum number per square metre in accordance with 5.4.2 and 5.4.3 divided by 2.

5.6.3
The bracing capacity of unreinforced earth bracing walls shall be as shown in table 5.7.

C5.6.3
For unreinforced earth walls with elastic response, 12 bracing units are equivalent to 1 kN lateral force at the ultimate limit state at the top plate level.
### Table 5.7 – Bracing capacity of unreinforced earth walls

<table>
<thead>
<tr>
<th>Wall length (L) (m)</th>
<th>Wall heights up to 3.3 m maximum</th>
<th>Bracing units provided</th>
</tr>
</thead>
<tbody>
<tr>
<td>280 mm thick wall</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>1.8</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>2.4</td>
<td>115</td>
<td></td>
</tr>
<tr>
<td>2.7</td>
<td>145</td>
<td></td>
</tr>
<tr>
<td>3.0</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td>&gt;3.0</td>
<td>20 x (L^2)</td>
<td></td>
</tr>
<tr>
<td>350 mm thick wall</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>1.8</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>2.4</td>
<td>145</td>
<td></td>
</tr>
<tr>
<td>2.7</td>
<td>185</td>
<td></td>
</tr>
<tr>
<td>3.0</td>
<td>225</td>
<td></td>
</tr>
<tr>
<td>&gt;3.0</td>
<td>25 x (L^2)</td>
<td></td>
</tr>
</tbody>
</table>

#### 5.7 Partially reinforced walls

#### 5.7.1
Partially reinforced walls shall only be used where the earthquake zone factor \(Z \leq 0.6\).

#### 5.7.2
Partially reinforced earth walls shall have one D12 vertical reinforcing bar at each end of bracing walls at a distance of 150 mm to 200 mm from the ends of the bracing walls as shown in figure 5.4.

#### 5.7.3
### Table 5.8 – Bracing capacity of partially reinforced earth walls

<table>
<thead>
<tr>
<th>Wall length (L) (m)</th>
<th>Wall heights (m)</th>
<th>Bracing units provided</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.4</td>
<td>2.7</td>
</tr>
<tr>
<td>1.2</td>
<td>157</td>
<td>NA</td>
</tr>
<tr>
<td>1.5</td>
<td>208</td>
<td>185</td>
</tr>
<tr>
<td>1.8</td>
<td>259</td>
<td>230</td>
</tr>
<tr>
<td>2.1</td>
<td>310</td>
<td>275</td>
</tr>
<tr>
<td>2.4</td>
<td>361</td>
<td>321</td>
</tr>
<tr>
<td>2.7</td>
<td>412</td>
<td>366</td>
</tr>
<tr>
<td>3.0</td>
<td>463</td>
<td>411</td>
</tr>
<tr>
<td>&gt;3.0</td>
<td>78 + 126 x L</td>
<td>36 + 123 x L</td>
</tr>
</tbody>
</table>

NOTE – Maximum wall heights are limited by 1.2.
Figure 5.4 – Reinforcing and dowels for reinforced and partially reinforced earth walls

- M16 threaded rod 6 mm fillet weld 50 long both sides to D12. M16 nut and 65 sq. plate washers
- D12 rod at each end for earth brick walls painted with zinc rich paint or galvanized or grouted in preformed hole. For rammed earth: ducted in 15 dia. pvc or polythene tube
- Horizontal reinforcement as per figure 5.5
- 150 to 200
- Floor level
- 50
- Reinforced concrete foundation (foundation reinforcing not shown)

Tighten nut 2 months and 12 months after construction of wall

- 75 mm² washer, and M16 nut
- Bond beam
- M16 threaded rod 50 long x 6 mm fillet welded both sides of D12
- D12 vertical rod at each end for earth brick walls painted with zinc rich paint, galvanized or grouted in preformed hole. For rammed earth: ducted in 15 dia. pvc or polythene tube. Welds to be painted with zinc rich paint

NOTE - Dowel connection to be provided within a max. of 300 either side of vertical D12 rod.
5.8 Reinforcement of earth walls 280 to 350 mm thick

5.8.1
Reinforced earth walls shall have one D12 vertical reinforcing bar at each end of bracing walls at a distance of 150 mm to 200 mm from the ends of the bracing wall as shown in figure 5.4.

5.8.2
Except as provided by 5.8.4, all reinforced adobe, rammed earth and pressed brick walls shall have vertical D12 reinforcing bars at the average and maximum spacings shown in table 5.9.

C5.8.2
Vertical reinforcing provided under 5.8.1 shall be included within the requirements of 5.8.2.

<table>
<thead>
<tr>
<th>Height of wall (m)</th>
<th>Average spacing (m)</th>
<th>Maximum spacing (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4</td>
<td>1.65</td>
<td>2.10</td>
</tr>
<tr>
<td>2.7</td>
<td>1.35</td>
<td>1.80</td>
</tr>
<tr>
<td>3.0</td>
<td>1.05</td>
<td>1.50</td>
</tr>
<tr>
<td>3.3</td>
<td>0.75</td>
<td>1.20</td>
</tr>
</tbody>
</table>

5.8.3
Except as provided by 5.8.4, all reinforced earth walls 280 to 350 mm thick shall have horizontal reinforcement which shall comprise one of the following alternatives:

(a) Type A – 5.3 mm diameter wire cut from 665 steel mesh reinforcing with 100 mm cross wires, at 450 mm centres in mortar joints as shown in figure 5.5; or

(b) Type B – Polypropylene geotechnical material such as polypropylene biaxial geogrid with square apertures 25 to 50 mm wide and with a quality control strength of 40 kN/m determined in accordance with BS 6906, cut into 200 mm wide strips at 450 centres in mortar joints as shown in figure 5.5. A 6 x 200 mm HDPE bodkin or 6 mm diameter minimum galvanized steel rod, 200 mm long threaded through the geogrid shall anchor the geogrid to the vertical reinforcing. The geogrid shall be pulled tight and fixed in place prior to being covered by earth wall material; or

(c) Type C – D12 bars at maximum 900 centres as shown in figure 5.4, 5.6 or 5.7; or

(d) As shown in figure 5.7 for reinforced rammed earth walls with concrete columns.

The geogrid may be tightened by use of a wider bodkin or larger diameter rod.

5.8.4
As an alternative to the provisions of 5.8.2 and 5.8.3, rammed earth walls may be constructed with no horizontal reinforcement embedded in the earth wall but with vertical D12 reinforcement provided in accordance with table 5.10.
Table 5.10 – Spacing of vertical D12 reinforcement in rammed earth walls without horizontal reinforcement

<table>
<thead>
<tr>
<th>Height of wall (m)</th>
<th>Average spacing (m)</th>
<th>Maximum spacing (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4</td>
<td>1.15</td>
<td>1.50</td>
</tr>
<tr>
<td>2.7</td>
<td>0.95</td>
<td>1.20</td>
</tr>
<tr>
<td>3.0</td>
<td>0.70</td>
<td>0.90</td>
</tr>
<tr>
<td>3.3</td>
<td>0.50</td>
<td>0.60</td>
</tr>
</tbody>
</table>

5.8.5
Each horizontal reinforcing member shall be in a single continuous length without laps between ends of bracing walls. Joints in horizontal reinforcing shall be located at vertical D12 rods at ends of bracing.

Figure 5.5 – Horizontal reinforcement for reinforced earth walls, Types A and B
Figure 5.6 – Horizontal reinforcement for reinforced earth walls, Type C
5.9 Reinforcement of rammed earth walls, 280 to 350 mm thick

5.9.1 Reinforced rammed earth walls shall be constructed in accordance with 5.8 and as shown on figure 5.4 with a D12 vertical reinforcing rod ducted within a 15 mm diameter PVC or polythene tube or as shown in figure 5.7 for walls with a concrete column on both sides of the rammed earth panel.

5.9.2 All reinforced rammed earth walls shall have horizontal reinforcement as provided for in 5.8.3.
5.9.3
For rammed earth walls with concrete columns the horizontal reinforcement shall be as shown in figure 5.8 at corners and ends of short return walls.

5.9.4
For rammed earth walls with concrete columns horizontal reinforcement comprising one R10 bar shall be provided under window openings as shown in figure 5.9.

5.9.5
Concrete columns between or at the ends of rammed earth panels shall not be poured until at least 7 days after the most recent panel has been rammed.
5.10 Earth walls without structural diaphragms

5.10.1 Where it is not possible to connect earth walls to a structural roof, all walls shall be laterally supported at the top by a bond beam connected to return walls as shown on figure 5.10. All walls supporting a first floor or a heavy roof shall be connected to a diaphragm. Earth walls without structural diaphragms shall be used only for single storey construction with a light roof.

5.10.2 Bond beams without a structural diaphragm shall be reinforced concrete where earthquake zone factor > 0.6, in accordance with section 7.

C5.10.2 Timber bond beams without a structural diaphragm may be used where earthquake zone factor > 0.6 if specifically designed. Such timber bond beams are outside the scope of this Standard.

5.10.3 Timber bond beams without a structural diaphragm in accordance with section 7 may be used only where earthquake zone factor ≤ 0.6. Timber bond beams with a structural diaphragm shall be in accordance

5.10.4 Return walls shall be provided to provide lateral restraint to bond beams. Such return walls shall contain earth bracing walls in accordance with 5.3 to 5.9.

5.10.5 The maximum length of a bond beam spanning between supporting return walls shall be 6.0 m. The bond beam shall be constructed in accordance with section 7 and as shown in figures 7.1, 7.2 and 7.3.

5.10.6 The maximum distance that a non-continuous concrete bond beam may extend past a return wall shall be 1.2 m as shown in figure 5.10.
Figure 5.10 – Layout of earth walls with concrete bond beams and without a structural diaphragm
5.10.7
Timber bond beams without structural diaphragms shall be continuous between return walls.

5.10.8
In addition to the requirements of 5.10.4, return bracing walls shall be provided as shown in table 5.11 and figure 5.10 for the total lengths of laterally supported wall with bond beam only and without a structural diaphragm.

Table 5.11 – Length of return walls for bond beam supported walls

<table>
<thead>
<tr>
<th>Laterally supported wall length (m)</th>
<th>Minimum return bracing wall length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5</td>
<td>1.2</td>
</tr>
<tr>
<td>6.0</td>
<td>1.5</td>
</tr>
<tr>
<td>7.5</td>
<td>1.8</td>
</tr>
<tr>
<td>9.0</td>
<td>2.1</td>
</tr>
<tr>
<td>10.5</td>
<td>2.25</td>
</tr>
<tr>
<td>12.0</td>
<td>2.4</td>
</tr>
</tbody>
</table>

5.11 Connection between walls and top plates or bond beams
Unreinforced, partially reinforced and reinforced earth walls shall be connected to bond beams and top plates by dowels as shown in figure 5.4. These dowels shall be in addition to hold down bolts required by 9.5.

C5.11
Dowels prevent bond beams or wall plates from sliding sideways from the walls under lateral loads.

6 STRUCTURAL DIAPHRAGMS

6.1 General

6.1.1
All structural diaphragms supporting earth walls against horizontal loads shall be constructed in accordance with this section.

6.1.2
Structural diaphragms complying with 6.2 and 6.3 shall in addition be constructed as follows:

(c) The minimum sheet size shall be 1800 mm x 900 mm except where the building dimensions prevent the use of a complete sheet;

(d) Each sheet shall be fastened along each edge to boundary members with nails at 150 mm centres and shall also be fastened to every intermediate framing member at 300 mm centres. Joints in sheet material shall be made over supports. 100 mm x 50 mm timbers fixed between joists with their top surfaces set to a common level shall be provided as necessary for this purpose. Refer to figure 6.1.

(e) Fastenings shall be not less than 10 mm from sheet edges.
6.1.2
This clause requires more stringent requirements for structural diaphragms supporting earth walls than NZS 3604. Structural diaphragms supporting timber walls may however be in accordance with NZS 3604.

Figure 6.1 – Sheet sarking diaphragm

6.1.3
Rafter, joist and floor sizes and details shall be in accordance with NZS 3604 unless noted otherwise in this Standard.

6.1.4
Rafters and joists shall be solid blocked at all supports and earth walls and ridge lines. Rafters and joists shall be solid blocked in accordance with NZS 3604.

6.1.5
Floor joists and diagonal strip flooring to give a 2 kN axial tension capacity. This includes rafter ridge connections on roofs.

6.2 Ceiling and roof diaphragms
Ceiling and roof diaphragms at the tops of earth walls shall not be steeper than 25° to the horizontal and shall be constructed of diagonal sarking complying with 6.4 or sheet sarking complying with 6.5.

6.3 Floor diaphragms
Floor diaphragms at the tops of earth walls shall be constructed of diagonal strip flooring complying with 6.4 or sheet flooring complying with 6.6.
6.4 Diagonal sarking
Diaphragms constructed using diagonal sarking shall consist of ex 150 mm x 25 mm or ex 100 mm x 25 mm boards of minimum finished thickness of 18 mm that are:
(a) Inclined at not less than 40° nor more than 50° to the floor joist, ceiling joist or ridge line;
(b) Laid in straight parallel lines fitted closely together;
(c) Fixed to each joist, truss or rafter that they cross;
(d) Have end joints butted over rafters or joists with end joints in adjacent boards staggered;
(e) Fixed with 2/60 x 2.8 mm nails at each joist or rafter spaced at maximum 900 mm centres;
(f) Fixed with 2/60 x 2.8 mm nails at ends;
(g) Laid to cover the entire area of the diaphragm except for penetrations not exceeding 500 mm square or 550 mm diameter with a total area of 1.0 m² or except for openings in accordance with 6.8;
(h) The edge members to which the sarking is fixed shall be continuous between return walls;
(j) As an alternative to 60 x 2.8 nails, 51 mm long, 7 gauge screws may be used.

6.5 Sheet sarking
Diaphragms constructed using sheet sarking shall:
(a) Be either:
   (i) Plywood not less than 7.5 mm thick three-ply;
       Nail fixed with 60 x 2.8 mm nails at 150 mm centres into framing member at sheet edges;
       Nail fixed infield of sheets with 60 x 2.8 mm nails at 300 centres on framing members spaced at no more than 450 centres (see figure 6.1); or
   (ii) High density internal ceiling plaster board lining not less than 9.5 mm thick and having a density not less than 880 kg per cubic metre and having a NZS 3604 rating in bracing units when fixed in place of not less than 100 Bracing Units per metre of element.
(b) Be fixed directly to rafters, ceiling battens, joists or trusses;
(c) Cover the entire area of the diaphragm except for openings in accordance with 6.8;

Refer to figure 6.1.

6.6 Sheet flooring
Diaphragms constructed using sheet flooring shall be:
(a) Plywood not less than 18 mm in thickness; or
(b) Any other wood based product not less than 17 mm thick having a density of not less than 600 kg per m³
and be nail fixed with 90 x 3.55 mm nails at 150 mm centres on framing members at sheet edges and infield of sheets spaced at 300 centres on framing members spaced at no more than 600 centres.
6.7 Connections of diaphragms to earth walls

6.7.1
All floor diaphragms shall be provided with boundary joists continuous between return walls and of dimensions not less than attached joists.

6.7.2
Diaphragms shall be connected to the bond beam or top plate at the top of the earth wall as shown in figures 6.2, 6.3 and 6.4.

6.7.3
Nail on plates shall be provided to connect the rafter blocking to the timber bond beam or top plate in accordance with table 6.1 and figures 6.2, 6.3, 6.4 and 6.5.

Table 6.1 – Connection of structural diaphragm to timber bond beam

<table>
<thead>
<tr>
<th>Building location</th>
<th>Spacing of nail on plates (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Where earthquake zone factor ≤ 0.6</td>
<td>1800 maximum</td>
</tr>
<tr>
<td>Where earthquake zone factor &gt; 0.6</td>
<td>900 maximum</td>
</tr>
</tbody>
</table>

Refer to figure 6.3 for details of nail on plates.

6.8 Openings in diaphragms

6.8.1
Continuous boundary members shall be provided to all sides of openings in diaphragms and shall be not less than the rafters or joists of the diaphragm construction.

6.8.2
The dimensions of any single opening in a diaphragm in each of the 2 principal directions at right angles shall not exceed the following percentages of the respective parallel overall dimension of the diaphragm:

(a) Where the opening is located wholly within the middle half area of the diaphragm as defined in figure 6.5 ............................................................................................................. 40 %

(b) Where the opening is located other than wholly within the middle half area of the diaphragm .................................................................................................................. 20 %

(i) Where all the openings are located wholly within the middle half area of the diaphragm ............................................................................................................. 16 %

(ii) Where any opening is located other than wholly within the middle half area of the diaphragm ............................................................................................................. 4 %
Figure 6.2 – Diaphragm fixing details

NOTE -
(1) Details similar at floor diaphragm.
(2) Floor joists blocked at midspan for spans over 3.6 m.
NOTE – These details apply to diaphragms with rafters, trusses and floor joists.

Figure 6.3 – Connection of diaphragms to walls
Figure 6.4 – Connection of ceiling diaphragms to earth walls for battened joists or trusses
Figure 6.5 – Connection of ceiling diaphragms to earth walls for sloping ceilings on underside of rafters
7 BOND BEAMS

7.1 General

7.1.1 Bond beams shall be provided at the top of all earth walls in order to:

(a) Assist in supporting lateral loads between adjacent transverse structural walls;

(b) Provide anchorage of floor and roof members;

(c) Tie the earth walls together.

7.1.2 The maximum height of earth walls between the footing and bond beam is specified in 1.2(c).

7.1.3 The connection of the bond beam to the wall shall be as shown in figure 5.4.

7.2 Bond beams with structural diaphragms

7.2.1 Where earthquake zone factor \( \leq 0.6 \) Timber or concrete bond beams shall be provided at the top of earth walls as shown in table 7.1.
Table 7.1 – Bond beams with structural diaphragms where earthquake zone factor ≤ 0.6

<table>
<thead>
<tr>
<th>Bond beam type and minimum size</th>
<th>Earth wall application</th>
<th>Maximum spacing between transverse bracing walls</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Timber</strong> 200 x 50 mm</td>
<td>All types</td>
<td>6.0 m</td>
</tr>
<tr>
<td><strong>Concrete</strong> Type A – 200 x 100 with 2/D12 and R6 ties at 400 centres</td>
<td>All types</td>
<td>6.0 m</td>
</tr>
</tbody>
</table>

NOTE – Timber bond beams may need to be wider to comply with 7.1.3.

7.2.2 Where earthquake zone factor > 0.6
Timber or concrete bond beams shall be provided at the top of earth walls as shown in table 7.2.

Table 7.2 – Bond beams with structural diaphragms where earthquake zone factor > 0.6

<table>
<thead>
<tr>
<th>Bond beam type and minimum size</th>
<th>Earth wall construction type</th>
<th>Maximum spacing between transverse bracing walls</th>
</tr>
</thead>
</table>
| **Timber** 200 x 75 mm 250 x 50 | All types | 6.0 m
| **Concrete** Type A 200 x 100 with 2/D12 and R6 ties at 400 centres | All types | 6.0 m
| **Concrete** Type E 250 x 175 with 2/D16 and R6 ties at 400 centres | All types | 6.0 m |

NOTE – Timber bond beams may need to be wider to comply with 7.1.3.

7.2.3 The connection of the bond beam to the wall and structural diaphragm shall be as shown in figures 6.3 and 6.4.

7.3 Bond beams without structural diaphragms

7.3.1 Where earthquake zone factor ≤ 0.6
Timber or concrete bond beams shall be provided at the top of earth walls as shown in table 7.3.
### Table 7.3 – Bond beams without structural diaphragms where earthquake zone factor ≤ 0.6

<table>
<thead>
<tr>
<th>Bond beam type and minimum size (mm)</th>
<th>Earth wall application</th>
<th>Maximum spacing between transverse bracing walls (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Light roof</td>
</tr>
<tr>
<td><strong>Timber</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200 x 50</td>
<td>Single storey for all types</td>
<td>3.0</td>
</tr>
<tr>
<td>200 x 75</td>
<td>Single storey for all types</td>
<td>3.8</td>
</tr>
<tr>
<td>200 x 100</td>
<td>Single storey for all types</td>
<td>4.5</td>
</tr>
<tr>
<td>250 x 50</td>
<td>Single storey for all types</td>
<td>4.0</td>
</tr>
<tr>
<td>250 x 75</td>
<td>Single storey for all types</td>
<td>4.8</td>
</tr>
<tr>
<td>250 x 100</td>
<td>Single storey for all types</td>
<td>5.4</td>
</tr>
<tr>
<td>300 x 50</td>
<td>Single storey for all types</td>
<td>4.8</td>
</tr>
<tr>
<td>300 x 75</td>
<td>Single storey for all types</td>
<td>5.7</td>
</tr>
<tr>
<td>300 x 100</td>
<td>Single storey for all types</td>
<td>6.0</td>
</tr>
<tr>
<td><strong>Concrete</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Type A</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200 x 100 with 2/D12</td>
<td>Single storey for all types</td>
<td>3.0</td>
</tr>
<tr>
<td><strong>Type B</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>250 x 100 with 2/D12</td>
<td>Single storey for all types</td>
<td>3.6</td>
</tr>
<tr>
<td><strong>Type C</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Type F</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>250 x 175 with 2/D20</td>
<td>Single storey for all types</td>
<td>6.0</td>
</tr>
</tbody>
</table>

**NOTE** –
(1) All ties to concrete bond beams without structural diaphragms shall be R6 at 200 centres.
(2) Timber bond beams may need to be wider to comply with 7.1.3.
7.3.2 Where earthquake zone factor > 0.6
Concrete bond beams shall be provided at the top of earth walls as shown in table 7.4.

<table>
<thead>
<tr>
<th>Bond beam type and minimum size (mm)</th>
<th>Earth wall application</th>
<th>Maximum spacing between transverse bracing walls (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Light roof</td>
<td>Heavy roof</td>
</tr>
<tr>
<td><strong>Concrete</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type D 250 x 150 with 2/D16 **</td>
<td>Single storey for all types</td>
<td>4.2</td>
</tr>
<tr>
<td>Type E 250 x 175 with 2/D16 **</td>
<td>Single storey for all types</td>
<td>4.5</td>
</tr>
<tr>
<td>Type F 250 x 175 with 2/D20 **</td>
<td>Single storey for all types</td>
<td>5.7</td>
</tr>
</tbody>
</table>

NOTE – All ties to concrete bond beams shall be R6 at 200 centres.

7.4 Intersection of timber bond beams

7.4.1 Intersections and joints between timber bond beams
Intersections and joints between timber bond beams shall be fixed as shown in:

(a) Figure 7.1 for timber bond beams with structural diaphragms;

(b) Figure 7.2 for timber bond beams without structural diaphragms.

7.4.2 For timber bond beams without structural diaphragms, joints in the bond beam shall be only at the corners and intersections of walls.
7.5 Laps in reinforcement of concrete bond beams
Laps in reinforcement of concrete bond beams shall be 40 times the bar diameter as shown in figure 4.4.

7.6 Size of reinforcement of concrete bond beams
The size and reinforcement of concrete bond beams shall be as shown in figure 7.3. Concrete cover to steel reinforcement and concrete strength shall be in accordance with 2.7.

Where there is a structural diaphragm, the R6 ties in concrete bond beams shall be at 400 mm centres.

Where there is no structural diaphragm, the R6 ties in concrete bond beams shall be at 200 mm centres.
Figure 7.3 – Concrete bond beams
7.7 Intersection of concrete bond beams
Reinforcement at concrete bond beam intersections shall be tied together with D16 L bars lapped 40 bar diameters as shown in figure 4.4.

7.8 Gable shaped walls
A raking bond beam shall be provided to top of every gable shaped wall and shall be connected to and be continuous with other adjoining bond beams. The size of the raking bond beam shall be determined in accordance with 7.2 to 7.3.

7.9 Timber gable end walls above earth walls

7.9.1 Where earthquake zone factor > 0.6
Where the earthquake zone factor > 0.6 and for single storey buildings with timber gable ends above earth walls as shown in figure 1.1(b) one of the following shall be provided:

(a) A timber bond beam with a flat ceiling diaphragm in accordance with section 6, or

(b) A concrete bond beam in accordance with 7.3, or

(c) A timber bond beam between the earth wall and the timber gable ends and with a roof diaphragm in accordance with section 6 not steeper than 25° and as shown in figure 7.4 and table 7.5.

7.9.2 Where earthquake zone factor ≤ 0.6
Where the earthquake zone factor (0.6 and for single storey buildings with timber gable ends above earth walls as shown in figure 1.1(b) one of the following shall be provided:

(a) A timber bond beam with a flat ceiling diaphragm in accordance with section 6, or

(b) A concrete or timber bond beam without a structural diaphragm in accordance with 7.3, or

(c) A timber bond beam between the earth wall and the timber gable ends and with a roof diaphragm in accordance with section 6 not steeper than 25° and as shown in figure 7.4 and table 7.5.

7.9.3 Intersections and joints between timber bond beams
Intersections and joints between timber bond beams between timber gable ends and earth walls shall be as shown in figure 7.2. There shall be no joints between transverse bracing walls.

| 200 x 500 | 3.6 |
| 200 x 75  | 3.8 |
| 200 x 100 | 4.3 |
| 250 x 50  | 4.5 |
| 250 x 75  | 4.6 |
| 250 x 100 | 5.4 |
| 300 x 50  | 5.5 |
| 300 x 75  | 5.8 |
| 300 x 100 | 6.0 |

NOTE – Bond beams may need to be wider to comply with 7.1.3.
8 LINTELS

8.1 General
Lintels shall be used over all openings and shall be constructed of timber in accordance with 8.2 or of concrete in accordance with 8.3.

C8.1
The lintel details provided in this section make provision for the drying shrinkage of earth walls.

8.2 Timber lintels

8.2.1
Timber lintels shall be seated a minimum of 300 mm on the earth wall on either side of the opening as shown in figure 8.1. Timber lintels narrower than the wall width shall bear on a 50 minimum thickness timber block the same width as the wall as shown in figure 8.1. For splayed reveals greater than 100 mm

C8.2.1
Solid timber lintels or box beams the full width of the wall may bear directly on the earth wall. See figure 9.3 for explanation of “splayed reveals”.

8.2.2
Timber lintels supporting timber framed walls, floor and roof above shall be in accordance with NZS 3604 and as shown in figure 8.1.
SECTION AT SUPPORT

Rafters, trusses or floor joists

Diaphragm

Continue top plate at opening

Timber lintel (50 or 100 thick)

Block between

200 x 50 block

Timber block on mortar bed 300 x 300 x 50 (or 100 thick) (adobe only)

Pre drill for 4 / 100 nails to adobe

D12 rod at bracing wall

SECTION AT LINTEL

Diaphragm

Rafters, trusses or floor joists

Continue top plate at opening

100 nails - 250 crs max.

Blocking between - 600 crs

20 finishing

Lintel as per NZS 3604 (May be 100 thick)

BOX BEAM LINTEL

Diaphragm

Rafters, trusses or floor joists

Timber top plate

ex 50

NOTE -
(1) Do not nail lintels to block under (or wall shrinkage may crack bricks).
(2) These details apply to lintels with rafters, trusses and floor joists.

Figure 8.1 – Timber lintels supporting timber framing above
8.2.3
Timber lintels supporting earth walls at gable end walls and roof loads only shall be as shown on figure 8.2. Timber lintels shall be supported at mid span during and for one month after construction of the wall above.

Figure 8.2 – Timber lintels supporting earth walls at gable ends

8.2.4
Timber lintels supporting both earth walls and first floor loads shall be specifically designed. Such lintels are outside the scope of this Standard.

8.3 Concrete lintels

8.3.1 Concrete lintels
Concrete lintels shall be continuous with the concrete bond beam on either side of the opening.

8.3.2
Where required the deepening of the concrete bond beam for the concrete lintel shall be as shown in figure 8.3.

8.3.3
Concrete cover to steel reinforcement and concrete strength shall be in accordance with 2.7.

8.3.4
Sizes, reinforcement and maximum spans of lintels supporting timber framed walls, floor and roof above shall be in accordance with tables 8.1 and 8.2 according to the snow load and figures 8.3, and 8.4. The different load cases of table 8.2 are shown in figure 8.5.
Figure 8.3 – Concrete lintel general arrangement

GENERAL ARRANGEMENT OF CONCRETE LINTELS WHERE BOND BEAM DOES NOT REQUIRE DEEPFING
(Types A1, B1, C1, D1, E1, AND F1)

Lap 40 dia. 300 min. Max. span as per table 8.2 300 min. Lap 40 dia.

Concrete bond beam with longitudinal reinforcement as per section 7
Longitudinal reinforcement continuous across lintel or lapped with 40 bar diameters with 50 top and side cover

Deepening of bond beam to form lintel with 50 bottom cover to longitudinal reinforcement as per figure 8.4

GENERAL ARRANGEMENT OF CONCRETE LINTELS WHERE BOND BEAM REQUIRES DEEPFING
(Types A2, B2, C2, D2, E2, AND F2)
### Table 8.1 – Concrete lintel details

<table>
<thead>
<tr>
<th>Type</th>
<th>Width</th>
<th>Depth</th>
<th>Longitudinal reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>200</td>
<td>100</td>
<td>2/D12</td>
</tr>
<tr>
<td>A2</td>
<td>200</td>
<td>200</td>
<td>4/D12</td>
</tr>
<tr>
<td>B1</td>
<td>250</td>
<td>100</td>
<td>2/D12</td>
</tr>
<tr>
<td>B2</td>
<td>250</td>
<td>200</td>
<td>4/D12</td>
</tr>
<tr>
<td>C1</td>
<td>250</td>
<td>100</td>
<td>2/D16</td>
</tr>
<tr>
<td>C2</td>
<td>250</td>
<td>200</td>
<td>4/D16</td>
</tr>
<tr>
<td>D1</td>
<td>250</td>
<td>150</td>
<td>2/D16</td>
</tr>
<tr>
<td>D2</td>
<td>250</td>
<td>200</td>
<td>4/D16</td>
</tr>
<tr>
<td>E1</td>
<td>300</td>
<td>175</td>
<td>2/D16</td>
</tr>
<tr>
<td>E2</td>
<td>300</td>
<td>250</td>
<td>4/D16</td>
</tr>
<tr>
<td>F1</td>
<td>300</td>
<td>175</td>
<td>2/D20</td>
</tr>
<tr>
<td>F2</td>
<td>300</td>
<td>250</td>
<td>4/D20</td>
</tr>
</tbody>
</table>

### Table 8.2 – Concrete lintels with 0.0, 0.5 or 1.0 kPa snow loads

<table>
<thead>
<tr>
<th>Type</th>
<th>Load case 1</th>
<th>Load case 2</th>
<th>Load case 3</th>
<th>Load case 1</th>
<th>Load case 2</th>
<th>Load case 3</th>
<th>Load case 1</th>
<th>Load case 2</th>
<th>Load case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>1.2</td>
<td>1.2</td>
<td>NA</td>
<td>1.2</td>
<td>0.9</td>
<td>NA</td>
<td>0.9</td>
<td>0.9</td>
<td>NA</td>
</tr>
<tr>
<td>A2</td>
<td>2.7</td>
<td>2.1</td>
<td>1.5</td>
<td>2.4</td>
<td>2.1</td>
<td>1.8</td>
<td>2.1</td>
<td>1.8</td>
<td>1.5</td>
</tr>
<tr>
<td>B1</td>
<td>1.2</td>
<td>1.2</td>
<td>NA</td>
<td>1.2</td>
<td>0.9</td>
<td>NA</td>
<td>0.9</td>
<td>0.9</td>
<td>NA</td>
</tr>
<tr>
<td>B2</td>
<td>2.7</td>
<td>2.1</td>
<td>1.8</td>
<td>2.4</td>
<td>2.1</td>
<td>1.8</td>
<td>2.1</td>
<td>1.8</td>
<td>1.5</td>
</tr>
<tr>
<td>C1</td>
<td>1.5</td>
<td>1.2</td>
<td>NA</td>
<td>1.2</td>
<td>1.2</td>
<td>NA</td>
<td>1.2</td>
<td>0.9</td>
<td>NA</td>
</tr>
<tr>
<td>C2</td>
<td>3.0</td>
<td>3.0</td>
<td>2.4</td>
<td>3.0</td>
<td>2.7</td>
<td>2.4</td>
<td>2.7</td>
<td>2.4</td>
<td>2.1</td>
</tr>
<tr>
<td>D1</td>
<td>2.7</td>
<td>2.4</td>
<td>NA</td>
<td>2.4</td>
<td>2.1</td>
<td>NA</td>
<td>2.1</td>
<td>1.8</td>
<td>NA</td>
</tr>
<tr>
<td>D2</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>2.7</td>
<td>3.0</td>
<td>2.7</td>
<td>2.4</td>
</tr>
<tr>
<td>E1</td>
<td>3.0</td>
<td>2.7</td>
<td>NA</td>
<td>2.7</td>
<td>2.4</td>
<td>NA</td>
<td>2.4</td>
<td>2.1</td>
<td>NA</td>
</tr>
<tr>
<td>E2</td>
<td>3.0</td>
<td>3.0</td>
<td>2.7</td>
<td>3.0</td>
<td>3.0</td>
<td>2.7</td>
<td>3.0</td>
<td>2.7</td>
<td>2.4</td>
</tr>
<tr>
<td>F1</td>
<td>3.0</td>
<td>3.0</td>
<td>NA</td>
<td>3.0</td>
<td>3.0</td>
<td>2.7</td>
<td>2.7</td>
<td>2.4</td>
<td>NA</td>
</tr>
<tr>
<td>F2</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>

**Load cases:**
1. Light roof only or light roof and walls only, figures 8.5(A) or (B).
2. Heavy roof only or heavy roof and walls only, figures 8.5(A) or (B).
3. Light roof and walls and timber floor or walls and timber floor only, figures 8.5(C), (D) or (E).
4. Specific design is required where a lintel supporting a roof has a loaded dimension of greater than 6.0 m, that is, when the supported roof member spans divided by 2 plus the eaves overhang is greater than 6.0 m.

NA – Not applicable.
8.3.6
Concrete lintels supporting earth walls shall be specifically designed. Such lintels are outside the scope of this Standard.

8.3.7
Where a concrete lintel is combined with a concrete bond beam and with a structural diaphragm, the bond beam reinforcement may be included in the area of the lintel reinforcement provided that the area of the lintel reinforcement exceeds the minimum area of the bond beam reinforcement.

8.3.8
Where a concrete lintel is combined with a concrete bond beam without a structural diaphragm, the reinforcement of the lintel shall be either:

(a) The maximum amount required by either the lintel or bond beam where the total length of the lintel lies within the middle two thirds of the bond beam span; or
Figure 8.4 – Concrete lintel sizes and reinforcement

NOTE:
(1) 50 cover to longitudinal reinforcing.
(2) All ties R6 at 200 crs. for A1 - F1 & 100 crs for A2 - F2.
(3) Refer to table 8.2 for maximum spans.
(4) All hooks 65 long.
Figure 8.5 – Load cases for concrete lintels
8.3.9
Where the lintel contains 4 longitudinal bars, this clause applies to the upper 2 bars only.

8.3.10
Laps for joining lintel and bond beam reinforcement shall be 600 mm.

8.3.11
No laps in reinforcement shall be within 300 mm of the opening.
9 WALL OPENINGS AND FIXINGS

9.1 Anchoring of joinery frames to walls
Windows and door frames shall be anchored securely to the earth wall. Details of anchor devices for anchoring door and window frames are shown in figure 9.1.

Joinery may be fixed to earth walls by screw or nail fixing to wooden inserts as per figure 9.1 or by masonry nail or non-expanding masonry screws to rammed earth or pressed brick walls.

C9.1
The drawing note “20 dia. hole for D12 vertical reinforcing rod (if required)” relates to the accommodation of wall reinforcing and is not a requirement for additional reinforcing for the frame fixing.

Anchor devices may be installed after construction but the most secure and economic devices are generally installed as the wall is being constructed.

Alternatively a rough frame may be built into the wall as it is being constructed and the “finished” frame fixed to this frame after the completion of wall and door construction although care must be taken to ensure that all necessary shrinkage can take place without “hang-up” on the rough frame. One method is to leave a gap of approximately 50 mm between the bottom of the rough frame and the concrete foundation.

9.2 Door and window details
Details are shown in figures 9.2 to 9.4. Vertical settlement occurs in earth walls and is to be provided for to prevent hang up and jamming of doors and windows.

C9.2
The detailing of doors and windows in earth walls requires special consideration when compared to conventional timber and masonry construction. The earth walls are thicker, surface of the earth wall less uniform and the wall material more fragile.
Figure 9.1 – Anchors for door, window and timber partition frames for earth walls
Figure 9.2 – Window head details
Figure 9.3 – Window jamb details
9.3 Fixings for timber framed walls

Fixings for timber framed walls shall allow for settlement of the earth wall. Details are shown in figure 9.5.

The vertical studs of the timber framed wall may be fixed to the earth wall as shown in figure 9.6 or with anchors in accordance with figure 9.1 or with three 12 mm diameter coach bolts through the end stud of the timber framed wall with a durable timber block set into the outside of the earth wall at top, mid-height and bottom. The top detail of figure 9.5 shall be used only for a non-loadbearing wall.
Figure 9.5 – Fixing of timber framed walls to allow for adobe earth wall vertical shrinkage
9.4 Arches

9.4.1
Earth bricks may be used to form arches over doors and windows as shown in figure 9.6.

**C9.4.1**
The bricks making up the arch may be specially shaped or may be parallel sided, however parallel sided bricks may present difficulties in achieving mortar joint thickness within the allowable range.

*Arches in rammed earth or poured earth are subject to specific design to eliminate their tendency to crack.*

![Figure 9.6 – Arch at door or window opening](image)

9.4.2
The maximum span of openings with arches shall be 1800 mm.

9.4.3
The height of the earth wall above the underside of the arch and below the bond beam at the top of the wall shall be a minimum of one quarter of the span of the opening or 300 mm, whichever is the greater.

9.5 Roof tie down bolts

9.5.1
Roof tie down bolts shall be provided for unreinforced earth walls where the earthquake zone factor \( \leq 0.6 \).

**C9.5.1**
*In reinforced earth walls and partially reinforced earth walls roof tie downs are provided by the vertical reinforcement and additional tie down reinforcement is not required.*
9.5.2
Roof tie down bolts shall be 12 mm diameter mild steel rods threaded at the top and anchored to a 8 mm thick 200 mm long by 100 mm wide mild steel plate embedded in the earth wall as shown in figure 9.7. These tie down bolts are in addition to dowels required by 5.11.

The depth of embedment in the walls, $D$, shall be as shown in table 9.1.
### Table 9.1 – Depth of embedment (D) of roof tie down bolts

<table>
<thead>
<tr>
<th>Building wind zone</th>
<th>Light roof (mm)</th>
<th>Heavy roof (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L and M H VH</td>
<td>500</td>
<td>Not needed</td>
</tr>
<tr>
<td></td>
<td>900</td>
<td>Not needed</td>
</tr>
<tr>
<td></td>
<td>1200</td>
<td>600</td>
</tr>
</tbody>
</table>

**NOTE –**
1. Bolts at 1200 mm maximum centres.
2. Wall thickness 280 to 350 mm.
3. Maximum span between walls – 7 m.
4. 12 mm diameter tie bolts with 50 x 50 x 6 mm square washer (see figure 9.7).
5. Maximum cantilevered eaves width 1200 mm.
6. Maximum width for veranda roof with tied down posts at outer edge, 2400 mm.

#### C9.5.3
*For greater maximum span or greater eaves width than those listed, specific design will be required.*

### 9.6 Flashings
Flashings, sills or other protrusions from the external face of a wall with earth wall below shall be detailed so as to prevent the concentrated flow of water over earth wall material.

### 10 CONTROL JOINTS

#### 10.1 General

**10.1.1**
Vertical control joints shall be provided in all earth walls except unstabilized adobe in accordance with NZS 4298.

**C10.1.1**
*Control joints are optional for unstabilized adobe walls.*

**10.1.2**
Bond beams which support diaphragms or otherwise provide lateral supports to walls shall be continuous through control joints. Lintels and their supports shall also be continuous through control joints.

**10.1.3**

**10.1.4**
Reinforced earth walls and partially reinforced earth walls shall contain a reinforcing rod immediately either side of the control joint.

### 10.2 Control joints for rammed earth walls
Control joints for rammed earth walls shall be in accordance with figure 10.1.

Mechanical keys shall be formed at each control joint and 25 x 25 mm acrylic adhesive impregnated poly foam strip shall be fixed as shown in figure 10.1 for the full height of the wall. The foam strip shall extend 100 mm along the floor slab to ensure a complete seal of the bottom of the construction joint.
Horizontal construction joints for rammed earth, where there is a break in the construction sequence of more than 24 hours shall be in accordance with figure 10.2.

**C10.2**

A “V” joint as shown in figures 10.1 and 10.2 may be formed on both wall faces as shown.

![Diagram of a "V" joint](image)

**NOTE** - Key former ex 100 x 50, (can be ex 150 x 50).
Figure 10.2 – Horizontal construction joint for rammed earth walls

10.3 Control joints for adobe and pressed brick walls

Figure 10.3 – Control joint for adobe and pressed brick

NOTE -
The matching rebates on each side of the mortar joint may be "V" shaped as shown or semi-circular in plan.
11 CINVA BRICKS

11.1 Scope

11.1.1 Buildings within the scope of this Standard which are constructed from cinva bricks shall comply with the additional provisions contained within this section.

11.1.2 Cinva bricks shall comply with the provisions of NZS 4298.

11.1.3 Exterior walls constructed from a single layer of cinva bricks shall have additional insulation to provide the minimum R values required by NZS 4218. This additional insulation is outside the scope of this Standard.

C11.1.3 The 140 mm thickness of cinva bricks acting alone does not provide sufficient thermal insulation to comply with Clauses E3 and H1 of the New Zealand Building Code and additional insulation is required.

11.2 Foundations

11.2.1 Clause 4.1.2 is to be replaced by the provision that the external wall face may be flush with the external footing face.

11.2.2 Clause 4.2.1 is to be replaced by the provision that the width of the footing shall be not less than 250 mm.

11.2.3 Footing details shall be in accordance with figure 11.1.

![Figure 11.1 – Cinva brick wall footings](image)
11.3 Bracing walls

11.3.1
The bracing demand shall be the values from tables 5.1 to 5.4 for 280 mm walls multiplied by 1.1.

11.3.2
In place of the provisions of table 5.5, the total bracing capacity in the building in each direction shall be at least:

(a) For single storey earth walls and light or heavy roof : 28 bracing units per square metre of floor area;
(b) For single storey earth walls with timber first floor and timber walled part storey in the roof space not exceeding 50 % of the ground floor and a light roof or with a full second storey with light cladding and a light roof : 45 bracing units per square metre of ground floor area.

11.3.3
The bracing capacity of cinva brick walls shall be those given by table 5.6 for 350 thick walls.

11.4 Wall reinforcing

11.4.1 Vertical reinforcing

11.4.1.1
Cinva brick walls shall have one D12 vertical reinforcing rod at each end of bracing walls at a distance of 75 to 230 mm from the ends of the bracing wall as shown in figure 5.4.

11.4.1.2
Vertical reinforcing by D12 bars shall be as given by table 11.1.

<table>
<thead>
<tr>
<th>Height of wall (m)</th>
<th>Spacing (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4</td>
<td>1.2</td>
</tr>
<tr>
<td>2.7</td>
<td>0.9</td>
</tr>
<tr>
<td>3.0</td>
<td>0.6</td>
</tr>
<tr>
<td>3.3</td>
<td>0.6</td>
</tr>
</tbody>
</table>

NOTE –
(1) Height of wall is measured between bottom of floor and underside of timber wall plate.

11.4.2 Horizontal reinforcing
Clause 5.8.3 shall apply with the following modifications.

(a) All horizontal steel shall be hot dip galvanized or alternatively it may be protected with 3 coats zinc-rich primer;

(b) Type A reinforcing shall not be used;

(c) Type B reinforcing shall not be used;
(d) Type C reinforcing shall have a 150 mm turn-down at the ends of the bar;
(e) Type D R10 reinforcing at 600 centres shown in figure 11.2 may be used.

![Figure 11.2 – Type D horizontal reinforcing (cinva brick only)](image)

11.5 Cinva brick walls without structural diaphragms
For cinva brick walls without structural diaphragms 5.10 shall apply except that 5.10.5 shall be replaced by the following:

The maximum length of a bond beam spanning between supporting return walls shall be 5.0 m measured centre-line-to-centre-line of the walls. The bond beam shall be constructed in accordance with section 7 and as shown in figure 7.1, 7.2 and 7.3.

11.6 Structural diaphragms
Section 6 shall apply with the following modifications.

(a) All timber diaphragm top plates shall be 150 x 50;
(b) Immediately beneath the timber top plates shall be a channel bond beam or a raking concrete 150 wide x 100 minimum height concrete bond beam containing a D12 longitudinal bar.

11.7 Concrete bond beams
The provisions of 7.5 to 7.8 shall apply with the following additional clause.

11.7.1 Concrete bond beams shall be as shown in figure 11.3 below.

![Figure 11.3 – Cinva brick walls – concrete bond beams](image)
11.8 Lintels

11.8.1 Clause 8.1 is replaced by the following:

Lintels shall be used over all openings and shall be constructed of timber in accordance with 11.8.3, of concrete or concrete masonry in accordance with 11.8.4, or cinva bricks in accordance with 11.8.5.

11.8.2 Gable ends

11.8.2.1 Gable walls shall be no higher than 3.3 m.

11.8.2.2 For the purposes of 11.8.3 and 11.8.5, lintels in gable walls shall be deemed to support a roof span, $S$, of 8.0 m of heavy roof.

11.8.2.3 Rafters shall run perpendicular to the ridge line.

C11.8.2.3 Gable end walls which support rafters running parallel to the ridge area are outside the scope of this Standard.

11.8.3 Timber lintels

11.8.3.1 The maximum height of cinva brick wall supported by a timber lintel shall be a single course consisting of a reinforced cinva channel bond beam.

C11.8.3.1 Timber infill framing with light cladding may be used in any gap between the lintel and the underside of the bond beam.

11.8.3.2 Timber lintel sizes shall be in accordance with NZS 3604 with the following modifications:

(a) For lintels of 0.9 to 2.1 m span, the allowable lintel span given in NZS 3604 for each timber size shall be reduced by 70 mm;

11.8.4 Concrete or concrete masonry lintels

Concrete or concrete masonry lintels shall be in accordance with NZS 4229.

11.8.5 Cinva brick lintels

Reinforced cinva brick lintels shall be as shown in figure 11.4, and shall have the spans shown in table 11.2. They shall support roofs only.
Figure 11.4 – Cinva brick lintels

Table 11.2 – Cinva brick lintels clear opening spans

<table>
<thead>
<tr>
<th>Distance $S$ (m)</th>
<th>8.0</th>
<th>12.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic snow load (kPa)</td>
<td>0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Roof type</td>
<td>Maximum clear span (m)</td>
<td></td>
</tr>
<tr>
<td>Light</td>
<td>4.5</td>
<td>3.6</td>
</tr>
<tr>
<td>Heavy</td>
<td>3.9</td>
<td>3.3</td>
</tr>
</tbody>
</table>

NOTE –
1. Refer to figure 8.5(A) for load case and definition of $S$.
2. Specific design is required where a lintel supporting a roof has a loaded dimension of greater than 6.0 m, that is, when the supported roof member spans divided by 2 plus the eaves overhang is greater than 6.0 m.

11.9 Wall openings and fixings
The provisions of section 9 are to be complied with in addition to the following provisions.

11.9.1 Timber top plates shall be fixed to cinva brick walls by either:

(a) M12 bolts set not less than 75 mm into the concrete and projecting sufficiently to allow for a washer and a fully-threaded nut above the timber;

(b) R10 steel dowels bent at least 90° set not less than 75 mm into the concrete and projecting sufficiently to allow for not less than a 75 mm length of the dowel to be clinched over the timber.

Such fixings shall be located not more than 300 mm from the end of the timber at corners of walls and not more than 1.4 m centres along the wall for M12 bolts and 900 mm centres for R10 dowels provided that each length of plate shall be fixed with not less than 2 such fixings.

11.9.2 Window and door frames may be fixed using 100 x 4.0 mm galvanized nails.

11.9.3 Where a timber top plate is not used the detail shown in figure 11.5 may be used for fixing rafters to a concrete bond beam.
11.10 Control joints

Figure 11.5 – Direct fixed rafters

Figure 11.6 – Cinva brick wall control joint – plan view
A1 Design Standards

A1.1
The following New Zealand Standard codes of practice were used in the preparation of the tables and construction details contained in this Standard.

1. NZS 4203:1992 *Code of practice for general structural design and design loadings for buildings*
2. NZS 4230:1990 *Code of practice for the design of masonry structures*
3. NZS 3101:1995 *Concrete structures Standard*
4. NZS 3603:1993 *Timber structures Standard*
5. NZS 4297:1998 *Engineering design of earth buildings*
6. NZS 3604:1990 *Code of practice for light timber frame buildings not requiring specific design*
7. NZS 4229:1986 *Code of practice for concrete masonry buildings not requiring specific design*

A1.2
A format similar to that in NZS 3604 and NZS 4229 was adopted for this Standard.

A2 Design strengths, factors and loads

A2.1
A summary of the design strengths, strength reduction factors and basic loads are shown in tables A1, A2 and A3. Standard grade earth wall construction in accordance with NZS 4297 was assumed.

**Table A1 – Design strengths (MPa)**

<table>
<thead>
<tr>
<th>Strength type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength (except for cinva bricks)</td>
<td>$f_e = 0.5$ MPa</td>
</tr>
<tr>
<td>Compressive strength of cinva bricks</td>
<td>$f_{es} = 2.0$ MPa</td>
</tr>
<tr>
<td>Shear strength of earth for limited ductile ($\mu = 2$ or $\mu = 1.25$ for cinva bricks) seismic loading</td>
<td>$f_{es} = 0.0$</td>
</tr>
<tr>
<td>Elastic response</td>
<td>$f_e = 0.09$ MPa</td>
</tr>
</tbody>
</table>

**Table A2 – Strength reduction factors**

<table>
<thead>
<tr>
<th>Type</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexure</td>
<td>$\phi = 0.80$</td>
</tr>
<tr>
<td>Shear</td>
<td>$\phi = 0.70$</td>
</tr>
<tr>
<td>Axial compression and bearing</td>
<td>$\phi = 0.60$</td>
</tr>
</tbody>
</table>
Table A3 – Basic load data

<table>
<thead>
<tr>
<th>Description</th>
<th>Load (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light roof and roof structure and ceiling dead load</td>
<td>0.4</td>
</tr>
<tr>
<td>Heavy roof and roof structure and ceiling dead load</td>
<td>0.8</td>
</tr>
<tr>
<td>Timber first floor including flooring, joists and ceiling dead load</td>
<td>0.5</td>
</tr>
<tr>
<td>Timber partitions dead load</td>
<td>1.0</td>
</tr>
<tr>
<td>Roof live load, NZS 4203</td>
<td>0.25</td>
</tr>
<tr>
<td>First floor live load, NZS 4203</td>
<td>1.50</td>
</tr>
<tr>
<td>Density of earth wall material (except cinva bricks)</td>
<td>18</td>
</tr>
<tr>
<td>Density of cinva brick earth wall material</td>
<td>19</td>
</tr>
</tbody>
</table>

A2.2
For the derivation of the tables for bracing demand in section 5 it was assumed that typically 30 % of the total building length was openings and that transverse earth walls were at typically 3 m centres. This is more conservative than the typical situation, and more conservative than seismic loads derived from an analysis of approximately 40 specifically designed earth houses using the 95 percentile value.

A3  Structural concept for earth walls

A3.1
Two earthquake zones were adopted in this Standard with the following 2 factors for the determination of seismic loads:

Earthquake zone factor ≤ 0.6, Z = 0.6

Earthquake zone factor > 0.6, Z = 1.2

A3.2
All earth walls for earthquake zone factor > 0.6 shall be reinforced.

A3.3
Earth walls in earthquake zone factor ≤ 0.6 may be reinforced, partially reinforced or unreinforced.

A3.4

second storeys were assumed to be distributed by concrete or timber bond beams or structural ceiling or roof or first floor diaphragms to transverse earth bracing walls.

A3.5
Designing for earthquake loading is always more critical than designing for wind for the wind exposure limitations imposed in this Standard.
A4 Lateral load provisions

A4.1
The structural ductility factor, $\mu$, was taken as 2.0 for reinforced earth walls except cinva bricks, as 1.25 for cinva bricks and as 1.0 for unreinforced and partially reinforced earth walls.

A4.2
The seismic design loads were based on NZS 4203 “intermediate ground”. Sites with soft ground are not within the scope of this Standard.

A4.3
The seismic coefficient for the design of the earth walls were as follows:

- Reinforced earth walls of limited ductility for earthquake zone factor > 0.6 .................. $C = 0.394$
- Reinforced earth walls of limited ductility for earthquake zone factor $\leq 0.6$ .................. $C = 0.197$
- Unreinforced and partially reinforced earth walls with elastic response for earthquake zone factor $\leq 0.6$ ................................................................. $C = 0.322$

A4.4
The in-plane strength of unreinforced walls is calculated assuming the following:

(a) 12 bracing units = 1 kN;

(b) The walls having no in-plane tensile strength but resist overturning by a triangular stress block generated by the wall’s self weight.

A4.5
The design of concrete bond beams was based on the assumption of 15 % openings within the length of the bond beam.

A5 Rammed earth without horizontal reinforcement
Some rammed earth practitioners have reported construction difficulties arising from the inclusion of horizontal steel.

Rammed earth walls without horizontal reinforcing are therefore permitted on the basis of increasing the seismic demand load corresponding to $\leq 2$ (limited ductile) to $\leq 1.25$ (reinforced masonry elastic response). This entails a seismic demand force increase of 41 %. Rather than inserting new “bracing demand” tables, and “bracing capacity” tables all increased by 41 %, and an increased vertical reinforcing area of the same amount, the BUs required/supplied tables have been left the same and increased design demand forces.

A6 Concrete lintels

A6.1
Concrete lintels were designed for the following load cases:

Load case 1 – roof only or roof and walls only with light roof, with maximum roof span $S = 12$ m and maximum floor joist span of 6 m.
Load case 2 – roof only or roof and walls only with heavy roof.

Load case 3 – floor and timber walls only and light roof, floor and timber walls only.

A7 Cinva ram brick walls

A7.1
In the case of cinva brick walls of 140 mm thickness, out-of-plane flexure loads under “Very High Wind” (design wind speed at ultimate limit state, \( V_u = 50 \text{ m/s} \)) make the greatest demand on the material, and exceed those of seismic zone factor \( z = 1.2 \) face loads. (Very High Wind can occur anywhere, as wind speeds are highly site-specific). To resist the Very High Wind out-of-plane loads it was necessary to set the design compressive strength at 2.0 MPa in the design of cinva brick, and corresponding values of production target strengths were set in the Materials and Workmanship Standard NZS 4298.

A7.2
Owing to the high design compressive strengths compared with unstabilized earth, it was possible to use the same footing details, and in the case of lateral in-plane load resistance, the same horizontal and vertical reinforcing requirements, as well as the same “bracing capacity” tables. “Bracing demand” tables are increased because, although cinva brick walls are lighter, total bracing demand is increased because \( \mu = 1.25 \) is used to provide for elastic response of the reinforced cinva brick masonry.

A8 Worked examples

A8.1
An illustrative worked example is provided in Appendix B to demonstrate the recommended method for
EXAMPLE 1 – SINGLE STOREY BUILDING WITH LIGHT ROOF

Figure B1 – Example 1 building
B1
A building in the earthquake zone > 0.6 has 280 thick walls, that are 2 700 high with light hip roof and ceiling structural diaphragm. Earth walls are at support line spacings of 4 500 in the north-south direction and 3 750 in the east-west direction. Distances are to the centreline of each support line.

Determination of bracing

Calculation for example 1

B1.1 Bracing demand for bracing support lines in north-south direction

Support line spacing 4 500 mm
Building length in north-south direction 7 500 mm

With reference to table 5.1 for single storey earth
with light roof bracing demand for exterior walls \[ \frac{424 + 636}{2} = 530 \text{ Bracing Units (BU)} \]
(Linear interpolation between 6 m and 9 m building lengths)

With reference to table 5.6
Nominally require 2/1.5 long walls or 1/2.4 long wall

Bracing demand for interior walls \[ \frac{619 + 928}{2} = 774 \text{ BU} \]
Nominally require 1/1.8 and 1/2.1 long walls

B1.2 Bracing demand for bracing support lines in east-west direction

External walls

Support line spacing 3 750 mm
Building length in east-west direction 13 500 mm

Linear interpolation between 3.0 m and 4.5 m support line

\[ = 877 \text{BU} \]

Nominally require 2/2.1 long walls or 3/1.5 long walls.
NZS 4299:1998

Interior walls

Linear interpolation between 3.0 m and 4.5 m support line spacings and 12 m and 15 m building lengths

\[
\text{Bracing demand for interior walls} = \left( \frac{962 + 1237}{2} + \frac{1203 + 1546}{2} \right) \frac{1}{2} = 1237 \text{ BU}
\]

Nominally require 2/2.4 and 1/2.1 long walls

B1.3 Minimum bracing capacity per square metre

With reference to table 5.5

Minimum No. of bracing units per m\(^2\) in north-south direction = 24 BU/m\(^2\)

Plan area of building (distances measured to external corners) = 107.2 m\(^2\)

Minimum bracing capacity in north-south direction = 107.2 x 24

= 2573 BU

Minimum bracing capacity in bracing units per m\(^2\) in east-west direction = \(\frac{24 + 28}{2} = 26\) BU

(Linear interpolation between 3.0 and 4.5 in support line spacings)

Minimum bracing capacity in east-west direction = 107.2 x 26

= 2787 BU

Note with reference to clause 5.4.2 bracing requirements for individual bracing support lines can be reduced up to 30 % provided the minimum bracing capacity in accordance with table 5.5 is achieved.

Refer to table B1 for summary of bracing demand.
Table B1 – Summary of bracing demand for example one

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Design criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>General</td>
</tr>
<tr>
<td>1</td>
<td>Earthquake zone</td>
<td>&gt; 0.6</td>
</tr>
<tr>
<td>2</td>
<td>Building type</td>
<td>SSLR</td>
</tr>
<tr>
<td>3</td>
<td>Wall thickness (mm)</td>
<td>280</td>
</tr>
<tr>
<td>4</td>
<td>Wall height (mm)</td>
<td>2700</td>
</tr>
<tr>
<td>5</td>
<td>Bracing demand table</td>
<td>5.1</td>
</tr>
<tr>
<td>6</td>
<td>Building length (centrel ine measurement) (mm)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Building external length (mm)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Building plan area (m²)</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Total wall area of earth gable end walls above nominal storey or wall height (mm) (4) multiplied by 50</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Minimum No. of BU's per m² (from table 5.5)</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Minimum No. of BU's 8x10 + 9</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Support line spacing (mm)</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>BU demand for exterior support lines</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>70 % of BU demand for exterior support lines</td>
<td></td>
</tr>
</tbody>
</table>
## Table B2 – Detailed wall bracing capacity calculations for example one

<table>
<thead>
<tr>
<th>Wall or bracing line label</th>
<th>BU demand</th>
<th>70% of BU’s</th>
<th>Wall ref No.</th>
<th>Wall length</th>
<th>Capacity BU’s</th>
<th>Totals</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>North – South A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>530</td>
<td></td>
<td>A1 1.5</td>
<td>1.5</td>
<td>309</td>
<td>371</td>
<td>927</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A2 1.5</td>
<td>1.5</td>
<td>309</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A3 1.5</td>
<td>1.5</td>
<td>309</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total 4.5</td>
<td></td>
<td>927</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>774</td>
<td></td>
<td>B1 3.6</td>
<td>1.5</td>
<td>309</td>
<td>542</td>
<td>1333</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>B2 2.4</td>
<td>1.5</td>
<td>309</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total 6.1</td>
<td></td>
<td>1333</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>774</td>
<td></td>
<td>C1 1.5</td>
<td>1.5</td>
<td>309</td>
<td>542</td>
<td>693</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>C2 1.8</td>
<td>1.5</td>
<td>309</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total 3.3</td>
<td></td>
<td>693</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>530</td>
<td></td>
<td>D1 1.8</td>
<td>1.5</td>
<td>309</td>
<td>371</td>
<td>768</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>D2 1.2</td>
<td>1.5</td>
<td>309</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>D3 1.8</td>
<td>1.5</td>
<td>309</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total 4.8</td>
<td></td>
<td>768</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total provided</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3721</td>
</tr>
<tr>
<td>Total required</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2573</td>
</tr>
<tr>
<td>East – West</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>877</td>
<td></td>
<td>X1 1.5</td>
<td>1.5</td>
<td>309</td>
<td>614</td>
<td>1236</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>X2 1.5</td>
<td>1.5</td>
<td>309</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>X3 1.5</td>
<td>1.5</td>
<td>309</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>X4 1.5</td>
<td>1.5</td>
<td>309</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total 6.0</td>
<td></td>
<td>1236</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>1237</td>
<td></td>
<td>Y1 1.5</td>
<td>1.5</td>
<td>309</td>
<td>866</td>
<td>1688</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Y2 2.4</td>
<td>1.5</td>
<td>309</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Y3 2.4</td>
<td>1.5</td>
<td>309</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Y4 1.5</td>
<td>1.5</td>
<td>309</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total 7.8</td>
<td></td>
<td>1688</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z</td>
<td>877</td>
<td></td>
<td>Z1 1.5</td>
<td>1.5</td>
<td>309</td>
<td>614</td>
<td>927</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Z2 1.2</td>
<td>1.5</td>
<td>309</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Z3 1.2</td>
<td>1.5</td>
<td>309</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Z4 1.2</td>
<td>1.5</td>
<td>309</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Z5 1.2</td>
<td>1.5</td>
<td>309</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total 609</td>
<td></td>
<td>927</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total capacity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3851</td>
</tr>
<tr>
<td>Total demand</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2787</td>
</tr>
</tbody>
</table>

Check for 5.3.8 – OK
**LEGEND**

- | D12 vertical reinforcing rod
- | Dowel connection through top plate and top of wall
- | Control joint

**NOTE -**

1. Refer to figure 5.5 for construction details of reinforced earth walls.
2. Refer to table 5.9 for spacing of vertical reinforcement.
EXAMPLE 2 – SINGLE STOREY BUILDING WITH LIGHT ROOF, UNREINFORCED EARTH WALLS IN EARTHQUAKE ZONE $\leq 0.6$

Building in the earthquake zone $\leq 0.6$. Other details are as for example 1 except for some wall lengths which have changed as shown on table B4.
Table B3 – Summary of bracing demand for examples two and three

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Design criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>General</td>
</tr>
<tr>
<td>1</td>
<td>Earthquake zone</td>
<td>≤ 0.6</td>
</tr>
<tr>
<td>2</td>
<td>Building type</td>
<td>SSLR</td>
</tr>
<tr>
<td>3</td>
<td>Wall thickness (mm)</td>
<td>280</td>
</tr>
<tr>
<td>4</td>
<td>Wall height (mm)</td>
<td>2700</td>
</tr>
<tr>
<td>5</td>
<td>Bracing demand table</td>
<td>5.1</td>
</tr>
<tr>
<td>6</td>
<td>Building length (centreline measurement) (mm)</td>
<td>7500</td>
</tr>
<tr>
<td>7</td>
<td>Building external length (mm)</td>
<td>7780</td>
</tr>
<tr>
<td>8</td>
<td>Building plan area (m²)</td>
<td>107.2</td>
</tr>
<tr>
<td>9</td>
<td>Total wall area of earth gable end walls above nominal storey or wall height (4) multiplied by 50</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>Minimum No. of BU’s per m² (from table 5.5)</td>
<td>12</td>
</tr>
<tr>
<td>11</td>
<td>Minimum No. of BU’s 8 x 10 + 9</td>
<td>1287</td>
</tr>
<tr>
<td>12</td>
<td>Support line spacing (mm)</td>
<td>4500</td>
</tr>
<tr>
<td>13</td>
<td>BU demand for exterior support lines</td>
<td>265</td>
</tr>
</tbody>
</table>
### Table B4 – Detailed wall bracing capacity calculations for example two

<table>
<thead>
<tr>
<th>Wall or bracing line label</th>
<th>BU demand</th>
<th>70 % of BU's</th>
<th>Wall ref No.</th>
<th>Wall length</th>
<th>Capacity BU's</th>
<th>Totals</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>North – South</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>265</td>
<td></td>
<td>A1</td>
<td>3.1</td>
<td>90</td>
<td>349</td>
<td>OK</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A2</td>
<td>0.9</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A3</td>
<td>3.6</td>
<td>259</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td>6.6</td>
<td>349</td>
<td>349</td>
<td>OK</td>
</tr>
<tr>
<td><strong>B</strong></td>
<td>387</td>
<td></td>
<td>B1</td>
<td>3.6</td>
<td>238</td>
<td>418</td>
<td>OK</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>B2</td>
<td>3.0</td>
<td>180</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td>6.6</td>
<td>418</td>
<td>418</td>
<td>OK</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>387</td>
<td></td>
<td>C1</td>
<td>2.4</td>
<td>115</td>
<td>295</td>
<td>OK</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>C2</td>
<td>3.0</td>
<td>180</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td>5.4</td>
<td>295</td>
<td>295</td>
<td>OK</td>
</tr>
<tr>
<td><strong>D</strong></td>
<td>265</td>
<td></td>
<td>D1</td>
<td>2.1</td>
<td>90</td>
<td>235</td>
<td>OK</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>D2</td>
<td>0.6</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>D3</td>
<td>2.7</td>
<td>145</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td>5.4</td>
<td>255</td>
<td>255</td>
<td>OK</td>
</tr>
<tr>
<td><strong>East – West</strong></td>
<td></td>
<td></td>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>1297</td>
<td></td>
</tr>
<tr>
<td><strong>X</strong></td>
<td>439</td>
<td></td>
<td>X1</td>
<td>2.1</td>
<td>90</td>
<td>385</td>
<td>OK</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>X2</td>
<td>2.1</td>
<td>90</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>X3</td>
<td>2.4</td>
<td>115</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>X4</td>
<td>2.1</td>
<td>90</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td>8.7</td>
<td>385</td>
<td>385</td>
<td>OK</td>
</tr>
<tr>
<td><strong>Y</strong></td>
<td>619</td>
<td></td>
<td>Y1</td>
<td>3.0</td>
<td>180</td>
<td>620</td>
<td>OK</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Y2</td>
<td>3.4</td>
<td>115</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Y3</td>
<td>2.7</td>
<td>145</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Y4</td>
<td>3.0</td>
<td>180</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td>8.4</td>
<td>620</td>
<td>620</td>
<td>OK</td>
</tr>
<tr>
<td><strong>Z</strong></td>
<td>439</td>
<td></td>
<td>Z1</td>
<td>1.8</td>
<td>65</td>
<td>390</td>
<td>OK</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Z3</td>
<td>1.5</td>
<td>45</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Z4</td>
<td>1.5</td>
<td>45</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Z5</td>
<td>2.7</td>
<td>145</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td></td>
<td></td>
<td>390</td>
<td>OK</td>
</tr>
<tr>
<td><strong>Total provided</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1395</td>
<td></td>
</tr>
<tr>
<td><strong>Total required</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1394</td>
<td>OK</td>
</tr>
</tbody>
</table>

Check for 5.3.8 – OK
NOTE - Refer to table B4 for dimensions of walls.

LEGEND

- Dowel connection through top plate and top of wall
- Control joint
EXAMPLE 3 – SINGLE STOREY BUILDING WITH LIGHT ROOF, PARTIALLY REINFORCED EARTH WALLS IN EARTHQUAKE ZONE $\leq 0.6$

B3
Building in the earthquake zone $\leq 0.6$. Other details are as for example 1. In table B5 bracing demand for the building is the same as for example 2 and is shown in table B3.
<table>
<thead>
<tr>
<th>Wall or bracing line label</th>
<th>BU demand</th>
<th>70 % of BU's</th>
<th>Wall ref No.</th>
<th>Wall length</th>
<th>Capacity BU's</th>
<th>Totals</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>North – South</strong></td>
<td></td>
<td></td>
<td>A1</td>
<td>1.5</td>
<td>185</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>265</td>
<td></td>
<td>A2</td>
<td>1.5</td>
<td>185</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A3</td>
<td>1.5</td>
<td>185</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td>4.5</td>
<td>555</td>
<td></td>
<td>OK</td>
</tr>
<tr>
<td>B</td>
<td>387</td>
<td></td>
<td>B1</td>
<td>3.6</td>
<td>479</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>B2</td>
<td>2.4</td>
<td>321</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td>6.0</td>
<td>800</td>
<td></td>
<td>OK</td>
</tr>
<tr>
<td>C</td>
<td>387</td>
<td></td>
<td>C1</td>
<td>1.5</td>
<td>185</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>C2</td>
<td>1.8</td>
<td>230</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td>3.3</td>
<td>415</td>
<td></td>
<td>OK</td>
</tr>
<tr>
<td>D</td>
<td>265</td>
<td></td>
<td>D1</td>
<td>1.8</td>
<td>230</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>D2</td>
<td>1.2</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>D3</td>
<td>1.8</td>
<td>230</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td>4.8</td>
<td>460</td>
<td></td>
<td>OK</td>
</tr>
<tr>
<td>Total provided</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2230</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total required</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1287</td>
<td></td>
<td>OK</td>
</tr>
<tr>
<td><strong>East – West</strong></td>
<td></td>
<td></td>
<td>X1</td>
<td>1.5</td>
<td>185</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td></td>
<td></td>
<td>X2</td>
<td>1.5</td>
<td>185</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>X3</td>
<td>1.5</td>
<td>185</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>X4</td>
<td>1.5</td>
<td>185</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total capacity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2735</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total demand</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1394</td>
<td></td>
<td>OK</td>
</tr>
<tr>
<td>Check for 5.3.8 – OK</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Z2120
NOTE - Refer to table B5 for dimensions of walls.

LEGEND

- D12 vertical reinforcing rod
- Dowel connection through top plate and top of wall
- Control joint