A MASONRY DESIGN STANDARD FOR USE IN DEVELOPING COUNTRIES

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SUMMARY

This paper seeks to demonstrate how a recently released design standard for concrete masonry buildings not requiring specific engineering design, NZS 4229:1999, has application not only in a New Zealand context, but that with very minor modification would readily serve as an appropriate design document in many developing countries. Research conducted in support of the document is briefly discussed, as is the composition of the standard and a supporting document containing several design examples. Key features of the design process are discussed, and changes necessary in order to use the document in other countries are detailed.

INTRODUCTION

Objective

The objective of this paper is to publicize the recently completed design standard, NZS 4229:1999 [SANZ, 1999a], produced by the Standards Association of New Zealand (SANZ) and related to the non-specific design of concrete masonry. This standard has been prepared for use in New Zealand, and targets new construction of partially and fully grouted single and double storey concrete masonry buildings. However, it is the authors opinion that as the document has been developed following considerable experimental verification, it is ideally suited for use in other seismically active countries. Furthermore, as the target audience of the document is tradespeople rather than qualified engineers, the standard appears to be written in an appropriate manner for use in countries where there may currently exist a comparatively poor understanding of the special detailing and construction requirements for simple masonry structures in order to survive significant earthquakes without resultant loss of life.

An accompanying user guide [NZCMA, 1999] prepared with joint funding from the New Zealand Concrete Masonry Association (NZCMA) and the Cement and Concrete Association of New Zealand (CCANZ) is also considered. It is emphasised that just as the design standard and user guide were written primarily for a non-technical audience, so to this treatment is aimed at presenting an overview rather than an in-depth assessment of the underlying engineering principles employed in the development of these documents. However, a discussion of relevant technical developments has been previously presented [Wilton, 1998] should this information be required.

Impact of earthquake damage

Several recent earthquakes, such as those centred in Spitak, Armenia in 1988 [Wyllie and Filson, 1989], Newcastle, Australia in 1989 [Melchers, 1990], Marathwada, India in 1993 [Momin et al., 1996], and Lijiang, China in 1996 [EERI, 1998] have clearly demonstrated that damage to unreinforced masonry construction can cause major loss of life and/or be very costly to repair. In countries where construction practice can be monitored, it is often found that such disasters result in changes to design standards or commonly accepted methods of construction. However, in developing countries where monitoring of construction practice may be more difficult to invigilate, or where a sound understanding of suitable seismic design practices has not yet been

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established, it follows that the provision of a design guide written in a suitable manner could be of significant benefit. It is postulated that NZS 4229:1999 is such a document, being suitable for use in conjunction with new construction in developing countries.

DEVELOPMENT OF NZS 4229:1999 AND SUPPORTING DOCUMENTS

Earlier Relevant Design Standards

The New Zealand Standard NZS 4229 "Code of practice for concrete masonry buildings not requiring specific design" [SANZ, 1986] was first introduced in 1986, having replaced NZS 1900 Chapter 6.2 [SANZ, 1964], and being modeled on NZS 3604 "Code of Practice for light timber frame buildings not requiring specific design" [SANZ, 1978]. Since 1986 when NZS 4229 was first released, considerable testing has been conducted providing additional information on the performance of concrete masonry, particularly when subjected to horizontal loads and when using partial grout-filling. From this testing it was recognised that there was considerable opportunity to streamline and simplify the design procedure. This has been accomplished with the release of the new version, NZS 4229:1999.

Research conducted in support of NZS 4229:1999

Several research projects were initiated in response to development of NZS 4229:1999. The first of these was conducted by Brammer and Davidson at the University Of Auckland [Brammer (1995), Davidson and Brammer (1996), Davidson (1996)], establishing the in-plane response of partially-grouted nominally reinforced concrete masonry walls. These researchers established that nominally reinforced concrete masonry walls have reliable in-plane strength, and exhibit limited reserve ductility ensuring satisfactory seismic response. This information was used to develop the bracing capacity tables presented in NZS 4229:1999.

Two projects were conducted at the University of Canterbury. The first of these was conducted by Singh, Cooke and Bull [Singh (1998), Singh et al. (1999)], who considered the out-of-plane response of a 9m wall between two end return walls. This study established that ductile response could be developed for long walls loaded out-of-plane, despite the fact that loading was generally well below wall capacity. This study was then extended [Xudong, 1998] to investigate the performance of two further walls having door and window openings at structurally inappropriate locations. One wall had doors at both ends of the loaded wall, isolating the return wall apart from the bond beam connection. The other wall included an 'around the corner' lintel. Both these later walls performed in a similar manner to the original wall. This information was used in the development of the bond beam criteria included in NZS 4229:1999.

The experimental studies detailed above have also been supported by analytical studies conducted by a structural consulting firm with expertise in the response of nominally reinforced masonry [Kelly, 1997a,b]. These studies established parallel performance to that observed in the laboratory, permitting modification of the model to investigate the performance of different wall configurations.

New Zealand Concrete Masonry Manual, Section 4.2

Because NZS 4229 was a new document in 1986, a guide to the use of that standard was prepared [NZCMA, 1988], including four design examples. Just as the more recent version of NZS 4229 has focused on a more streamlined document, so too has a new design guide been prepared on the basis of producing a smaller document retaining its versatility. In part, this has been accomplished by assuming that much of the material being innovative and potentially misunderstood in 1986 is now widely accepted, so that a comprehensive treatment of that material is now unwarranted.

CONTENT OF NZS 4229:1999

Credit for NZS 4229:1999

NZS 4229:1999 has been prepared by the Standards Association of New Zealand. The primary parties responsible for completion of the document, as listed in the standard, are: CCANZ, NZCMA, Institute of Professional Engineers New Zealand, NZ Institute of Architects, Building Research Association of NZ, NZ Masonry Trades Employers Association, Local Government New Zealand, and Firth Industries Ltd.

Scope of document

NZS 4229 is a simplified document appropriately used to design a reduced range of concrete masonry buildings. As detailed in section 1 of the Standard, only building with the following limitations may be designed using NZS 4229:

a) Buildings which are not dedicated to the preservation of human life or for which the loss of function would have a severe impact on society, and/or which do not as a whole contain people in crowds, and/or which are not publicly owned and have contents of high value to the community.
b) Buildings where the total height from the lowest ground level to the highest point of the roof does not exceed 10m.
c) Buildings whose floor plan does not exceed 600m^2 for a single storey, 250m² for a two-storey masonry building, 350m² for a two-storey building where the upper storey is constructed of timber and the external wall of the lower storey is of masonry, or 250m² for a two- or three-storey building where the upper storey or stories is constructed of timber, the lower storey is constructed of masonry, and the top storey is contained within a roof space.
d) Buildings where the live load on suspended floors does not exceed 2 kPa for buildings and balconies, or exceed 1.5 kPa for three-storey buildings.
e) Buildings where the roof is constructed of timber, complies with NZS 3604, and has a slope which does not exceed 45°.
f) Buildings where suspended timber floors comply with NZS 3604 and suspended concrete floors comply with NZS 3101 [SANZ. 1995] and do not have a dead load exceeding 4.5 kN/m².

Buildings which do not comply with the criteria listed above must be specifically designed using NZS 4230:1990 [SANZ, 1990]. Note also that in addition to restrictions on building type, Section 3 of the Standard details specific site conditions which are required before the Standard may be used.

Layout of document

NZS 4229:1999 has thirteen chapters and three Appendices:

1. Scope and interpretation
2. General
3. Site requirements
4. Bracing demand
5. Wall bracing capacity
6. Footings
7. Foundation walls and concrete slab on ground
8. Walls
9. Diaphragms
10. Bond beams
11. Lintels
12. Masonry veneer wall coverings
13. Shrinkage

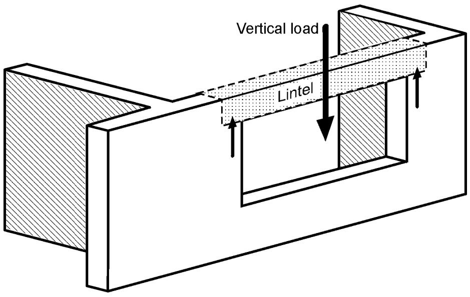
A. Design examples
B. Cantilever walls
C. Masonry retaining walls

Notably, flow charts demonstrating the design process are included in appendix A, guiding the designer through the various sections of the document.

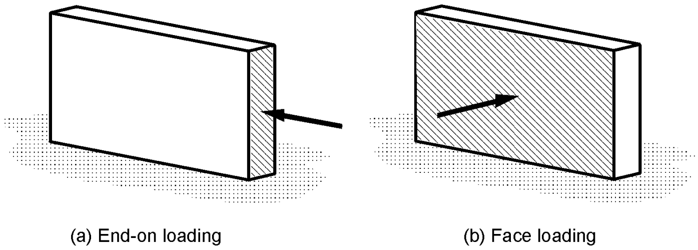
CONTENT OF NZCMM SECTION 4.2

Layout of document

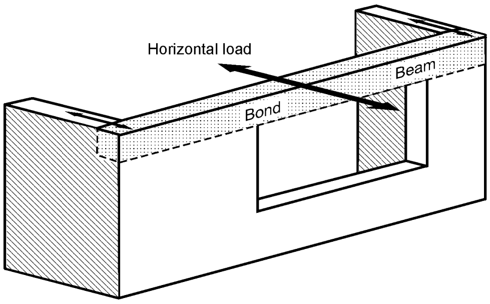
This guide is divided into three sections. The first section defines the scope of the Standard, with buildings outside the scope being the subject of specific design. Section 1 also introduces the basic structural elements of a masonry building, and how these elements interact to transmit loads through the building. These basic elements are illustrated in Figure 1, demonstrating the suitability of the document for use by tradespeople not familiar with structural seismic design.



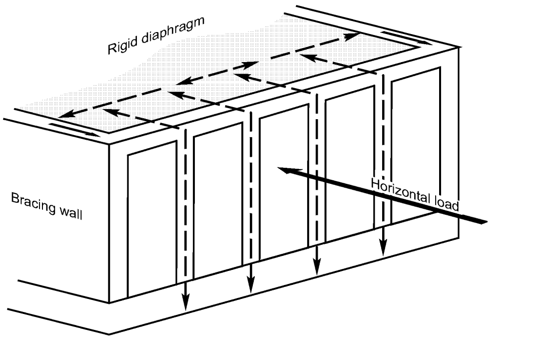
(i) Lintel load actions



(ii) Wall load actions



(iii) Bond beam actions

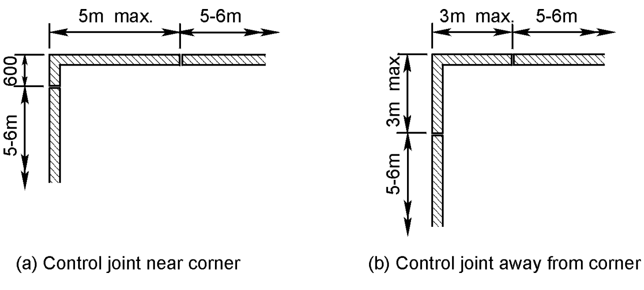


(iv) Vertical wall reinforcement and diaphragm action

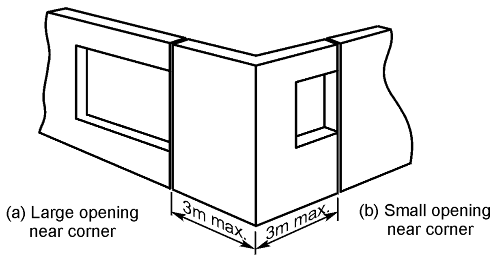
Figure 1: Structural Elements within a masonry building.

Note that the illustrations in Figure 1 aid in demonstrating that just as lintels support gravity loads (Fig. 1i), the horizontal force on face loaded walls (Fig. 1iib) may be transmitted to stiff end walls (Fig. 1iia) through the use of a bond beam (Fig. 1iii). Distributed vertical wall reinforcement aids in transmitting load from the walls to the bond beam and foundation (Fig. 1iv), and the use of a rigid diaphragm (Fig. 1iv) alleviates the demand on the bond beam, particularly for long bond beam spans. This covers the basic fundamentals of a simple concrete masonry structure designed to withstand earthquakes.

Section 2 of the guide contains a number of design notes clarifying aspects of the design procedure. These design notes are referred to in Section 3, where several design examples of increasing complexity are considered. An example of design notes related to the positioning of shrinkage control joints is shown in Figure 2. These control joints assist in defining the geometry of individual panels (bracing panels) along a wall (bracing line). Using the information contained in section 5 of the standard, the capacity of the structure to withstand lateral earthquake forces may be established.



(i) Plan View

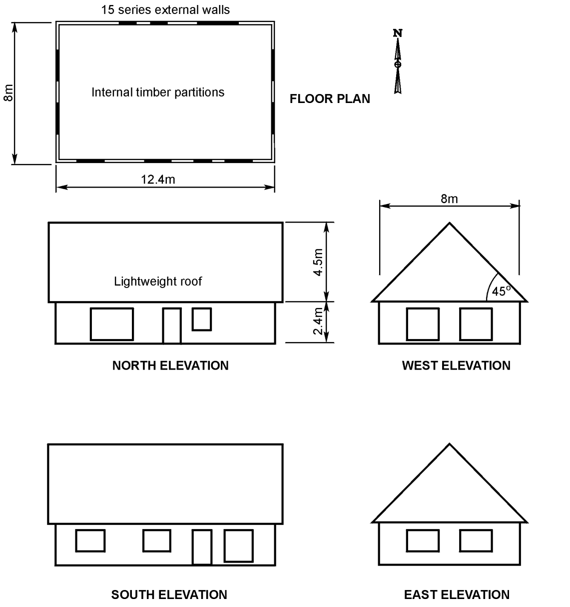


(ii) Elevation

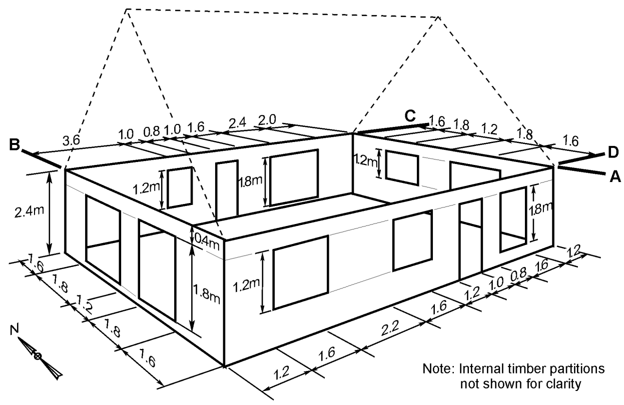
Figure 2: Design notes demonstrating the application of shrinkage control joints.

Design Examples

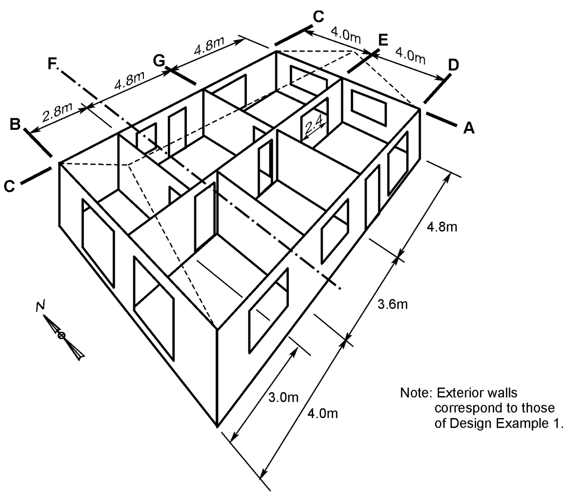
Section 3 of the user guide contains several design examples of increasing complexity, demonstrating effective use of NZS 4229:1999. A typical design example of a single storey masonry house is illustrated in Figure 3, showing two options dependent on the presence (Fig. 3ii) or absence (Fig. 3iii) of internal masonry structural walls. The location of shrinkage control joints and individual bracing panels for the perimeter of the structure is shown in Figure 3iv.



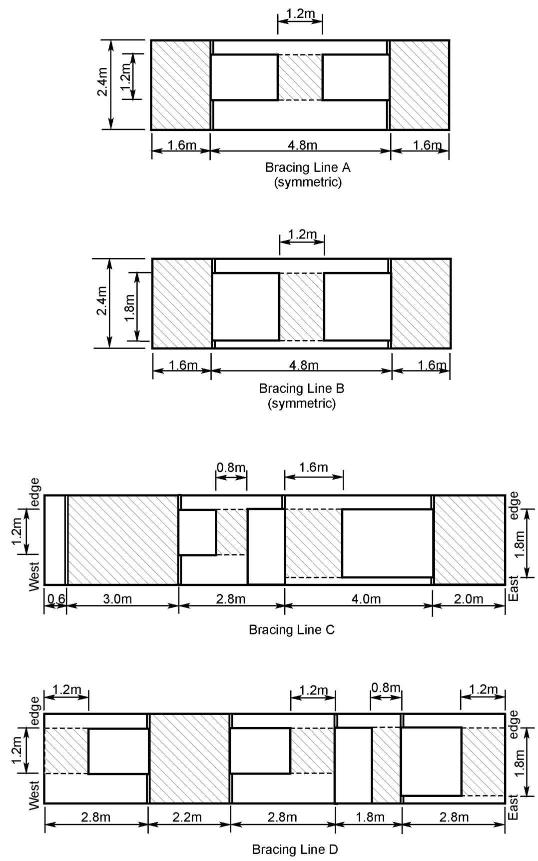
(i) Details of simple masonry structure



(ii) View of structure relying on ceiling diaphragm



(iii) View of structure with internal masonry walls



(iv) Individual bracing lines for (ii) above

Figure 3: Details of a typical design example [NZCMA (1999).

Design procedure

As identified in appendix A of the standard, the design process is approximately as listed below:

1. Identify location, geometry of the structure, and site conditions. Establish that the project falls within the scope of NZS 4229:1999. If not, use specific design.
2. Based on the details identified in (1) above, the required bracing capacity can be established for the given seismic zonation and maximum wind loading of the region.
3. Based on the distance between structural walls, it may be established whether a structural diaphragm is required.
4. Based on the geometry of the structure and the location of wall penetrations, shrinkage control joints can be positioned, bracing lines identified and the capacity of individual bracing panels considered to ensure that the structure has sufficient lateral capacity to exceed demand. It may be necessary to use solid grout-filling, or wider concrete masonry units, in order to ensure sufficient capacity.
5. Bond beams and diaphragms are designed.
6. Lintels are designed, and are amalgamated with the bond beam design where possible.
7. Additional wall reinforcement, such as at shrinkage control joint and wall penetrations, is detailed (see Figure 4).
8. The footing design is completed.

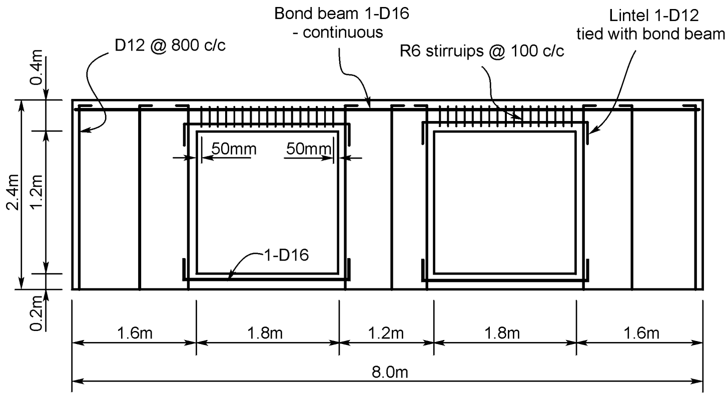


Figure 4: Typical wall reinforcement layout (shrinkage control joints not shown for clarity).

APPLICATION OF NZS 4229:1999 IN OTHER COUNTRIES

From the information presented above it may be established that NZS 4229:1999 incorporates the findings from a number of recent experimental studies, and uses a simple yet effective design process. The construction of partial grout-filled concrete masonry is expected to involve a level of construction competency readily achieved in developing countries, and the document has been prepared in a manner suitable for tradespeople. In order for the document to be used in countries other than New Zealand, it merely remains to develop maps of regional seismicity and wind loading. These are further discussed below.

Wind load zonation

It has been established that in most parts of New Zealand, the lateral loading on masonry structures is dependent on earthquake rather than wind loading. However, this may not be the case in countries regularly subjected to seasonal hurricanes or cyclones, so that it is conceivable that wind loading will be an important feature of design. In such cases, maximum wind loads on structures should be prepared in a manner similar to that presented in NZS 3604:1999 [SANZ, 1999b], which identifies the magnitude of wind loading on structures for two orthogonal directions, as shown in Figure 5.

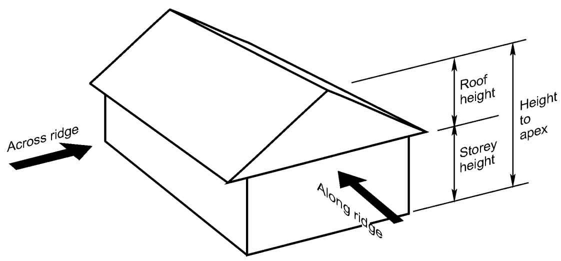


Figure 5: Treatment of lateral wind loading.

Seismic zonation

The regional seismic zonation adopted in NZS 4229:1999 is developed from NZS 4203:1992 [SANZ, 1992] and identifies three levels of seismicity. Zone A corresponds to regions of high seismicity, and given New Zealand seismicity would appear to be an equally appropriate classification for highly seismic zones in any other country. At the other extreme, Zone C is classified as regions of low seismicity (in the New Zealand context) and should be viewed as appropriate for regions well removed from active faults, where attenuation will result in less severe loading. A stylized regional seismicity map for a fictitious country, suitable for use with NZS 4229:1999, is illustrated in Figure 6.

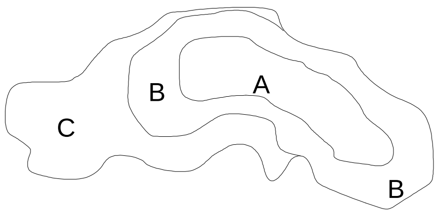


Figure 6: Simple representation of a typical regional seismicity map for use with NZS 4229:1999.

CONCLUSIONS

1. NZS 4229:1999 has been developed following significant research into the performance of concrete masonry structural components.
2. NZS 4229:1999 is a suitable concrete masonry design standard for use in developing countries.
3. In order to use NZS 4229:1999 in countries other than New Zealand it is necessary to develop regional wind and seismic zonation charts.
4. Section 4.2 of the New Zealand Concrete Masonry Manual is a useful design aid complementing NZS 4229:1999.

ACKNOWLEDGEMENTS

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