THREE NEW DESIGN TOOLS FOR RESIDENTIAL CONCRETE MASONRY CONSTRUCTION IN NEW ZEALAND

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ABSTRACT

Residential construction in New Zealand has traditionally been based on timber materials, which have been available in abundance and for which the skill base is extensive. Many architectural designers are enthusiastic about the use of alternative building systems such as concrete masonry, but research has shown that there is a lack of readily available design and detailing guidance, particularly for those with limited experience in using the material. Three new design guides have been prepared for the New Zealand construction industry to make it easier and more cost efficient to make use of concrete masonry in the context of residential construction.

Research carried out at two New Zealand universities has demonstrated the conservative nature of structural requirements in the New Zealand Standard for non-specific engineering design of concrete masonry buildings. As a result the cost of concrete masonry construction has been higher than necessary, which may also act as a barrier to greater use of the material. These issues have been addressed through a rewriting of NZS 4229. The revision incorporates a significant reduction in structural requirements. To facilitate the use of the Standard, a user guide has been prepared and seminars have been presented throughout the country.

The Cement and Concrete Association of New Zealand identified a lack of information for designers and builders in the detailing and construction methods of concrete masonry construction in a residential context. This concern has been addressed through the preparation of a detailing and specification guide for concrete construction in New Zealand, based on research carried out at Victoria University of Wellington. The guide considers all formats of concrete construction and concrete masonry is a significant part of it.

This paper presents the background to the preparation of these design resources. In addition, it considers current areas of research directed at improving the range and quality of information available for builders and designers of concrete masonry homes in New Zealand. Finally the suggestion of extending the documents to apply in some other countries is made.

KEYWORDS:

Non-specific design; concrete masonry; design innovation; design guide

INTRODUCTION

The objective of this paper is to publicise the recently published design guides for designing and constructing concrete masonry homes and buildings of similar scale. These guides include
1. NZS 4229:1999 [SANZ, 1999a] prepared by the Standards Association of New Zealand,
2. Section 4.2 of the New Zealand Masonry Manual [Ingham & Gjerde, 1999] published by the New Zealand Concrete Masonry Association
3. Residential Concrete Detailing and Specification Guide [Gjerde, 2000] published by the New Zealand Concrete Masonry Association (NZCMA) and the Cement and Concrete Association of New Zealand (CCANZ).

The target audience for the documents is architectural design professionals and trades people rather than qualified engineers. All three design guides have been prepared for the New Zealand context and target new construction of partially and fully grouted single and double storey concrete masonry buildings. While the documents are all published by different entities, there has been a coordination of effort and objectives to ensure a consistency between them as well as coordination with NZS 3604: Non Specific Design Guide For Lightweight Timber Construction.

It is emphasised here that just as NZS 4229 and Section 4.2 of the Masonry Manual were written at a non-technical level for design professionals, so too this paper 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.

CONTEXT

During the brief history of colonial settlement of New Zealand it is the single-family home that has become the predominant building type. Timber was in abundant supply when early settlers arrived and the skills to construct in timber were quickly developed. The relative flexibility of timber construction allows it to perform well in earthquakes when used in one and two storey buildings. Research carried out by the Building Research Association Of New Zealand (BRANZ) suggests that 94% of new home construction in 1998-99 was based on the lightweight timber framing method [Page, 1999]. Guides for the appropriate structural and architectural uses of timber are abundant, with the primary one being on NZS 3604 “Code Of Practice For Light Timber Frame Buildings Not Requiring Specific Design” [SANZ, 1999b]. This NZ Standard is well known and used by those who design and build in timber.

The BRANZ surveys suggest that less 2 % of new homes are built using concrete masonry. Considerable research has been published on the thermal and comfort benefits of concrete masonry when incorporated effectively into the design of a home [Donn, 1990], yet with increasing awareness of this fact the number of homes built using the material has not increased significantly during the past 10 years. Surveys conducted by CCANZ in 1998 and 1999 [Thomas, 1999] have identified a high level of acceptance by designers of concrete masonry being a suitable building material for homes in New Zealand, yet in those same surveys a lack of appropriate design tools was noted. The tools needed by the design profession include thermal design information along with costing and waterproofing guidance. The information most needed is on design and construction detailing. The research also identified the need to educate builders in the materials and methods of constructing using concrete masonry. While there is considerable knowledge of concrete masonry walls used in large commercial structures, most builders in New Zealand specialize in either commercial work or domestic scale construction. It is acknowledged that the detailing of smaller scale buildings is more demanding on the builder and the skills are seen to be deficient.

DEVELOPMENT AND APPLICATION OF NZS 4229:1999

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 modelled on NZS 3604. 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.

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.

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

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 buildings with the following limitations may be designed using NZS 4229:

1. 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.
2. Buildings where the total height from the lowest ground level to the highest point of the roof does not exceed 10m.
3. Buildings whose floor plan does not exceed 600m² 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.
4. 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.
5. Buildings where the roof is constructed of timber, complies with NZS 3604, and has a slope which does not exceed 45°.
6. Buildings where suspended timber floors comply with NZS 3604 and suspended concrete floors comply with NZS 3101 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. 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.

NZS 4229:1999 has thirteen chapters and three Appendices. These set out the design requirements for footing up to bond beams, bracing demand and capacity of wall elements as well as shrinkage control. A small section on durability has been included. Notably, flow charts demonstrating the design process are included in the appendices, guiding the designer through the various sections of the document.

The structural requirements of NZS 4229 are considerably less than those found in the previous document. These changes have been justified through empirical testing as set out above and were to make the use of concrete missionary in houses more cost competition with other materials.

**DEVELOPMENT OF NZCMM 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.

(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. 1iiib) 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.

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

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.

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.
8. The footing design is completed.

(i) Details of simple masonry structure  (ii) View of structure relying on ceiling diaphragm
DEVELOPMENT OF DETAILING AND SPECIFICATION GUIDE

A guide to the architectural detailing of concrete residential scale buildings was conceived by the Cement and Concrete Association of NZ as part of their Cement Your Ideas in Concrete (CYIOC) programme. CCANZ identified through its market research (Thomas, 1999) that the lack of relevant and unbiased information on the architectural design and detailing as well as construction of concrete homes was preventing many designers and builders from entering the market. While the design of large commercial buildings in concrete is well understood in the industry, most architects and designers recognise that at a residential scale the detailing is different. Contractors align themselves as either commercial or domestic scale builders and most are either unwilling, or find it difficult, to move between the two. For those who are willing there can be a very steep learning curve. A need has clearly been established for the writing of the guide.

Research was carried out in the form of observation and evaluation of existing building practices in addition to consultation with builders, designers, material suppliers and homeowners. The research findings were developed into written information and drawn details, which was then subjected to a peer review by participants in the concrete masonry construction industry. The design of details is a very subjective matter in that there are many ways in which to solve weatherproofing, wind proofing, durability and construction issues. Guiding the designer is the aesthetic presentation of the detail and how it works with the overall concept of the house. The peer reviewers were asked to set aside any bias in design and to concentrate on the practical issues of the detail.

Figure 3: Details of a typical design example [NZCMA (1999)].
The Detailing and Specification Guide is organised into five categories which are

1. General Information
2. Design Issues
3. Specification Issues
4. Construction Issues
5. A selection of details

The concrete masonry section forms one section of the guide, which also includes three other formats of concrete construction. Its target audience is both designers and builders of concrete masonry homes.

The details form the backbone of the publication, presenting common details for wall to ground floor, wall to suspended floor and wall to roof connections, all of which incorporate a variety of proprietary and purpose made floor systems available in New Zealand. The details incorporate all the structural principles of NZS 4229 so as to present a consistent picture of concrete masonry construction at this scale (Figures 4 and 5). The details indicate various strategies for insulating the building envelope. This is one of the major detailing considerations when constructing in concrete masonry. Common door and window openings are detailed using timber, aluminium and steel joinery. A commentary is included with each of the details to point out the construction requirements and performance characteristics.

It would not be possible to produce a guide of all detailing scenarios in concrete masonry. An objective of the research team was to present a broad picture of construction options. It has been stressed to users that while the details present a range they would perhaps be better used as the foundation from which the designer can develop his or her own details. To this end the details are drawn to scale and can in the first instance be used as a template for further development by the designer or builder. All the details are presented as examples of best practice and it is clear that much of the built work surveyed by the research team feel short of that objective, giving further encouragement to the research team.

Figure 4: A detail indicating an externally insulated building envelope
CONTINUING DEVELOPMENT

The need to continue development of these three design tools has been acknowledged by the CCANZ. All three authors have been involved in presentation of these tools to industry participants throughout New Zealand since publication. While the main purpose has been to disseminate the information in an interactive manner, another objective has been to open the documents to wider scrutiny and input. Minor modifications to NZS 4229 have been issued by SANZ and Section 4.2 of the Masonry Manual has also been modified and reprinted. The research team for the Detailing and Specification Guide has, since it was released, been assessing feedback in order to modify and extend the document. It is likely that the project will continue to grow in the form of a database of details and other information on concrete masonry construction.

Subsequent versions of the Detailing and Specification Guide are planned to be released in CD-Rom format, acknowledging the penetration of computer technology into all facets of the construction industry. It is also planned to place the guide, in its entirety, on the CCANZ web site, making it possible for potential users to view and download the details, which can then be modified to suit their particular project.

Further design and construction information is currently being researched and will eventually be published in a similar manner. The areas being considered are appropriate thermal design and weatherproofing systems for concrete masonry walls.

RELEVANCE OF THE GUIDES IN THE BUILDING REGULATORY SYSTEM

The building industry in New Zealand has since 1992 been operating under a performance based building code [BIA, 1995]. At the time of writing the Code it was seen that allowing for innovation and flexibility could help keep building costs down. This has largely proven to be true.

The Building Code, while setting the performance criteria to be met, also presents a list of documents that, when followed, provide a means of compliance. NZS 4229: 1999 has been approved as a Means...
of Compliance for structural (Clause B1), durability (Clause B2) and external moisture (Clause E2) requirements of concrete masonry construction falling within the scope of the document. Section 4.2 of the Masonry Manual has no status under NZBC as it is simply a guide to the appropriate use of NZS 4229:1999. As is the case with most New Zealand Standards used in the building industry, NZS 4229:1999 is often interpreted to be the required means of complying with the Code. Specific design, either in conjunction with certain aspects of NZS 4229:1999 or completely separate, is generally accepted by the Territorial Authority approving the building work.

One of the areas the NZBC is weak currently is in presenting specific information that will fulfil the requirements for durability and protection from ingress of rainwater. New materials and methods of building are continually entering the marketplace. While single materials or systems can be evaluated and approved for use in New Zealand conditions, the weakness often occurs at the junction with another material. Manufacturer’s information often includes details that are well developed in terms of their specific product but do not consider the adjoining materials well. By not having even a minimum set of details that are known to work as a reference, those who administer the NZBC on a daily basis are often called upon to make judgements concerning marginal details. The Building Industry Authority is receptive to reviewing and approving for use details that provide a comprehensive solution to the durability and waterproofing requirements of the Code. The process of gaining approval of the Detailing and Specification Guide has begun. Once it has been approved it will be able to be cited by applicants for Building Consent and, more importantly, followed by the builder with the knowledge that the minimum requirements of the Code will be met.

RELEVANCE OF THE GUIDES IN OTHER COUNTRIES

The three design guides present an excellent opportunity to raise the level of understanding and fill a need 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 standard and the user guide to be used in countries other than New Zealand, it merely remains to develop maps of regional seismicity and wind loading.

While the Detailing and Specification Guide has been based on those materials that are readily available in New Zealand, concrete masonry is universally available. The details presented are all within the competency levels of developed countries and many of those which are developing. The concepts and principles of planning, detailing and constructing a small concrete masonry building would not change, although it would be necessary to substitute the locally available profiles such as windows and doors. As the details are all drawn in AutoCAD format, such changes before reprinting are made more feasible.

CONCLUSIONS

The recent publication of three guides for the design and construction of concrete masonry has filled a longstanding need in the New Zealand construction industry.

NZS 4229:1999 has been developed following significant research into the performance of concrete masonry structural components.

Section 4.2 of the New Zealand Concrete Masonry Manual is a useful design aid, complementing NZS 4229:1999.
The Residential Concrete Detailing and Specification Guide has been written as a guide to building designers and builders and considers the appropriate non-structural details for masonry construction. The scope of this guide is such that research will continue and be published at appropriate intervals.

The reduction in structural requirements in NZS 4229 are such that there may be incentive to introduce it as a masonry design standard in countries with seismic conditions similar to those of New Zealand.

These guides have been very well received by the construction industry which suggests that it is important to continue to research which will lead to the publication of guides in areas, such as weatherproof coatings and construction planning.

NZS 4229:1999 is currently approved as a Means of Compliance under the performance based New Zealand Building Code. It is planned to have the Detailing and Specification Guide approved to similar status. This will help fill a significant void in the building regulation process and prevent substandard detailing of small-scale concrete masonry buildings.

REFERENCES


SANZ, 1964. “NZS 1900 Chapter 6, Division 2 Construction requirements for buildings not requiring specific design - masonry”. Wellington, New Zealand.


