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CONFINED MASONRY NETWORK: AN OVERVIEW OF GUIDELINES AND INITIATIVES

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Abstract

In January 2008, an International Strategy Workshop on the Promotion of Confined Masonry was organized at Kanpur, India, by the National Information Centre of Earthquake Engineering, India; the World Housing Encyclopedia project of EERI and IAEE; and the World Seismic Safety Initiative. A group of international experts from India, the USA, Switzerland, Peru, Mexico, China, Indonesia, and Canada created a Confined Masonry Network with two major objectives: i) to improve the design and construction quality of confined masonry where it is currently in use, and ii) to introduce it in areas where it can reduce seismic risk. The web site www.confinedmasonry.org was created as a growing repository of resources related to confined masonry construction, including training materials, guidelines, and research papers. Besides compiling the existing resources on confined masonry, the group committed to developing global guides for seismic design and construction of confined masonry structures, state-of-the-art papers on confined masonry and research needs, and several awareness initiatives. This paper presents an overview of confined masonry design and construction, featuring the guidelines for design of low-rise confined masonry buildings (up to two-storey high) that were developed by masonry experts from 13 countries. Two other guidelines have been recently completed, a construction guideline for architects and engineers, and a simple illustrated guide for builders and house-owners. Currently in production is a seismic design guideline for engineered confined masonry buildings, which is expected to fill the gap in this area, since most international guidelines are focused on a prescriptive design approach.

Keywords: confined masonry; seismic safety; developing countries; guidelines; construction; education

1. Introduction to Confined Masonry

1.1 What is Confined Masonry?

Several past earthquakes have revealed the intrinsic poor performance of unreinforced masonry buildings as well as non-ductile reinforced concrete (RC) frame construction, particularly in developing countries where such construction is common. This has resulted in high human and economic losses and prompted a need for alternative building technologies with improved seismic performance. One such technology is confined masonry, which consists of masonry walls confined by horizontal and vertical RC tie-columns and tie-beams that enclose the masonry wall panels on all sides. Application of confined masonry does not require advanced construction skills and so it can be used as an alternative to both unreinforced masonry and RC frame construction.

Confined masonry construction has evolved through an informal process based on its satisfactory performance in past earthquakes. The first reported use of confined masonry construction was in the reconstruction of buildings destroyed by the 1908 Messina, Italy earthquake (M 7.2), which killed over 70,000 people. Confined masonry construction has been practiced in Mediterranean Europe (Italy, Slovenia, and Serbia), Latin America (Mexico, Chile, Peru, Argentina, and other countries), the Middle East (Iran), south Asia (Indonesia, India, and other countries), and the Far East (China). The first large-scale application of engineered confined masonry construction recently took place in India. Thirty-six confined three- and four-storey confined masonry buildings were constructed at the campus of the Indian Institute of Technology (IIT) Gandhinagar in the State of Gujarat, as shown in Fig. 1. It is important to note that confined masonry construction has been practiced in countries and regions of extremely high seismic risk. Several examples of confined masonry construction around the world, from Argentina, Chile, Iran, Peru, Serbia, and Slovenia, are featured in the World Housing Encyclopedia [1].

Fig. 1 – A confined masonry building under construction at the IIT Gandhinagar campus, India (Photo: S. Brzev)

1.2 The Confined Masonry Network

In January 2008, an International Strategy Workshop on the Promotion of Confined Masonry was organized at Kanpur, India, by the National Information Centre of Earthquake Engineering, India; the World Housing Encyclopedia project of EERI and IAEE; and sponsored by the World Seismic Safety Initiative and Risk Management Solutions Inc. A group of international experts from India, the USA, Switzerland, Peru, Mexico, China, Indonesia, and Canada created a Confined Masonry Network with two major objectives: to improve confined masonry design and construction practices where it is currently in use, and to introduce it in areas where it can reduce seismic risk. A web site [2] was created to provide a growing repository of resources related to confined masonry construction, including training materials, guidelines, and research papers. Besides compiling the existing resources on confined masonry, the group committed to developing global guides for design and construction of confined masonry buildings and a state-of-the-art report on research needs. The network provides a platform for discussion on issues related to confined masonry design and construction in seismic areas.

At this stage, the design guide and two construction guides for low-rise confined masonry buildings have been completed, while the guide for design of engineered buildings is currently being developed. This paper presents an overview of the guides and their key features.

2. Design Guidelines for Low-Rise Non-Engineered Confined Masonry Buildings

The first guideline published by the Confined Masonry Network in August 2011 was the *Seismic Design Guide for Low-Rise Confined Masonry Buildings* (referred hereon as the Guide) [3]. The Guide was developed by thirteen international experts in earthquake engineering and confined masonry structures. The recommendations in the Guide are based on design codes and research studies from countries and regions where confined masonry construction is well established, including Mexico, Peru, Chile, Argentina, Iran, Indonesia, China, Algeria, and Slovenia.

The Guide contains prescriptive design recommendations for one- and two-story buildings that are constructed without technical input of qualified technicians. Since the Guide is intended to be used by non-engineers, engineering calculations are not required for its application. Differences in seismic hazard level, construction materials and practices such as different floor/roof systems (light wooden roof versus reinforced concrete slabs) have been addressed by the Guide.

The Guide is divided into three chapters. Chapter 1 provides an overview of confined masonry construction and its components, and includes a discussion on the mechanisms of seismic response for confined masonry buildings. Chapter 2 presents general requirements related to confined masonry construction, including architectural planning considerations and materials. The heart of the document is Chapter 3, which outlines prescriptive design recommendations for low-rise confined masonry buildings, including recommendations for wall layout and density, minimum size requirements for structural components, and reinforcement size and detailing. The Guide also summarizes seismic design provisions for confined masonry buildings from relevant international codes.

2.1 Recommendation Highlights

The recommendations can be grouped into three general areas: material types and mechanical properties, wall design recommendations, and details related to confining RC elements (tie-beams and tie-columns).

2.1.1 Material Types and Mechanical Properties

Most types of standard masonry units can be used for confined masonry construction. Research and post-earthquake observations indicate that confined masonry walls built with solid units (e.g. clay bricks) perform better than walls with multi-perforated units (e.g. clay tiles) or hollow concrete blocks. Thus the Guide includes recommendations related to the amount of perforations or holes within masonry units, expressed as a fraction of the unit's gross cross-sectional area.

Minimum recommended compressive strengths for various masonry units and mortar types are included in the Guide, as are minimum compressive strengths for concrete and masonry units and minimum yield strengths for reinforcing steel in RC confining elements. These strengths are based on a survey of minimum material strengths specified in building codes and technical guidelines from several countries. When technical information on locally available units is available, the Guide recommends that this data be used by qualified technicians to adjust the specifications accordingly.

2.1.2 Wall Design Recommendations

Wall density index is a key indicator of seismic safety for low-rise confined masonry buildings, as confirmed by a study following the 2010 Maule, Chile earthquake [4]. The wall density index is a ratio of the total wall area in each orthogonal direction to the building plan area. The required wall density index for a particular building is determined from the Simplified Method based on the Mexican building code [5]. It depends on the seismic hazard, soil type, number of stories, masonry shear strength, building weight, and gravity load-bearing capacity. The following alternative approaches are available for checking whether the wall density index for a building is within the recommended limits: 1) the value should be compared to the maximum value recommended in the Guide, or 2) the required wall density index can be calculated from design equations. This method can be used in lieu of a detailed analysis for regular buildings (without significant torsional effects), and when shear failure mechanism is predominant for confined masonry walls. Thus walls with large openings or with height/length ratios of 1.5 or higher are not counted as confined masonry walls.

The presence of openings of significant size can have a negative influence upon seismic resistance of confined masonry walls, according to research evidence and reports from past earthquakes. The effect of openings on seismic performance of confined masonry structures depends on their size and location. Ideally, confining elements (RC tie-columns) should be provided on the sides of the openings, but that is not always feasible. The Guide includes recommendations for how to account for unconfined wall openings in the wall density analysis.

The Guide also includes recommendations for wall thickness, height, height/thickness ratio, and spacing. It also provides recommendations for parapets and gable walls.

2.1.3 Confining Reinforcing Concrete Beams and Columns

Reinforced concrete tie-columns and tie-beams are effective in improving stability and integrity of masonry walls for in-plane and out-of-plane earthquake effects. These elements prevent brittle seismic response of masonry walls and protect them from complete disintegration even in major earthquakes. Confining elements, particularly tie-columns, contribute to the overall building stability for gravity loads. In order to ensure proper confinement, the tie-columns and tie-beams must be carefully detailed and constructed. To assist in this, the Guide includes several recommendations for tie-columns and tie-beams, including sizes, locations, spacing, reinforcement details, and concrete placement.

Adequate bond between a masonry wall and the adjacent tie-columns is important for satisfactory earthquake performance and for delaying undesirable cracking and separation at the wall-to-tie-column interface. Bonding can be achieved by either toothing at the wall-to-tie-column interface or with reinforcing dowels. Toothing is the most common approach. The Guide includes recommended details for toothing construction, which are illustrated in Fig. 2.

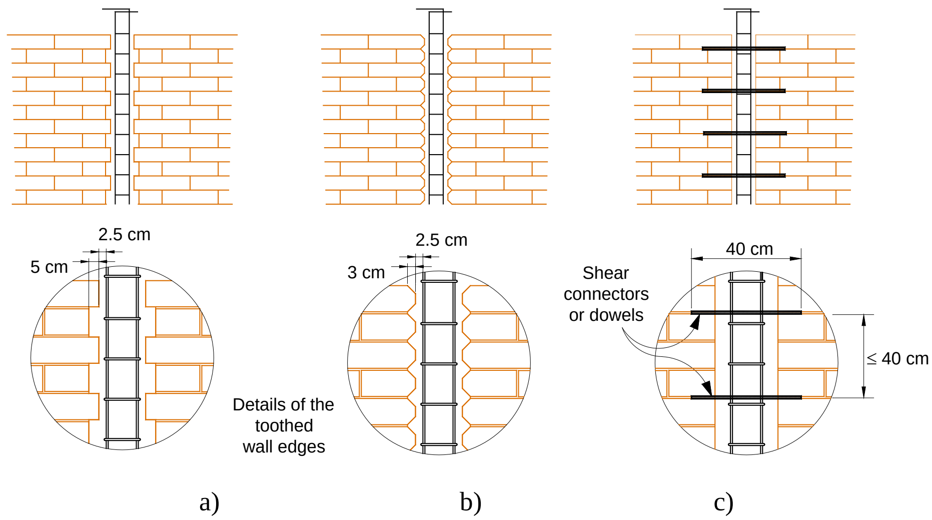


Fig. 2 – Toothing in confined masonry walls: a) machine-made hollow units, b) hand-made solid units, and c) provision of horizontal reinforcement when toothing is not possible [3]

3. Construction Guidelines for Non-Engineered Confined Masonry Buildings

Concurrent to the development of design guidelines for confined masonry, another group of international experts developed companion construction guidelines [6]. These guidelines address the needs of small-scale builders, technicians, government staff, architects, as well as non-government organizations involved in post-disaster reconstruction. The guidelines were written with users with various professional backgrounds in mind, including trained workers. The focus is on the practical detailing of confined masonry construction. The recommendations were drawn from guidelines developed in several countries, including Pakistan [7], Peru [8], and Indonesia [9, 10], as well as reconstruction experience from the 2010 Haiti earthquake [11]. The goal of the construction guidelines is to compile the best practices into one document that can then be adapted for use in specific countries.

3.1 Recommendation Highlights

The recommendations are grouped into four general areas: layout and configuration, materials, workmanship, and quality control. The following paragraphs will focus on construction practice aspect of the guide.

3.1.1 Materials

Masonry units should have a uniform color and regular form and should not be twisted, bent, or lumpy. Where possible, the units should be manufactured in a plant rather than at the construction site due to superior quality control. In some cases, it is possible to assess quality through simple field tests. For example, bricks can be field tested by a three-point load test where an average person stands on the brick to see if it will break.

Portland cement is usually readily available in countries where confined masonry is constructed. Hydrated lime has been used in concrete mixes with positive results. River or crushed quarry sand between 1 and 4 mm particle size is recommended. Beach sand should be avoided because of its chlorine content. Both the sand and aggregate should be washed and cleaned of mud, dirt, and debris prior to mixing them with the cement.

The use of ribbed reinforcing steel is recommended for longitudinal reinforcement in concrete tie-columns and tie-beams. Smooth bars can still be used for stirrups. It is important to protect the steel from weather prior to installation, particularly in moist environments where unprotected steel can quickly start to rust.

3.1.2 Construction Practice

Confined masonry walls are relatively stiff and solid compared to light frame systems and are not easily adaptable to changes in building elevation such as sloping sites. Thus it is recommended that the building site be leveled as much as possible prior to construction. Confined masonry walls are also vulnerable to cracking due to differential settlement. For that reason, if the building site consists of expansive soils or uncompacted fill material, either the soil should be excavated and replaced or a lighter frame system should be considered instead of confined masonry.

The foundations for confined masonry buildings are usually either cast-in-place concrete footings or stone footings with a concrete plinth beam on top, directly beneath the masonry. Concrete spread footings are recommended beneath RC tie-columns in multi-story structures and single-story buildings with concrete roofs. If the building is one-story and the roof is framed with light material such as wood, the builder can consider not installing a spread footing and instead have the columns bearing on the RC plinth beam or continuous concrete strip footing typical for wall construction.

Once the foundation is placed, the next phase of work is the construction of masonry walls. It is recommended to place the masonry units one course at a time, using a plumb to maintain vertical alignment. The walls should be built using a staggered or running bond instead of a stacked bond due to its superior seismic performance. Clay bricks have a tendency to be dry so it is recommended that they be soaked in clean water prior to placement as illustrated in Fig. 4, or else they may dry out the mortar by absorbing the water from it, turning the mortar into a powder.

The reinforcement for the RC tie-beams and tie-columns is placed next. It is critical that tie-beam-to-tie-column joints remain intact in order to maintain confinement of masonry walls in post-cracking stage. For that reason the longitudinal reinforcement in both the tie-beams and tie-columns should be fully developed at the beam to column connections with 90 degree hooks lapped with the intersecting reinforcing. Similar hooks are also recommended at beam-to-beam connections, as illustrated in Fig. 3. In some countries it is custom to terminate the longitudinal steel with 180 degree hooks and no laps. This configuration should be avoided.

Transverse reinforcement in the form of ties is required for both the tie-beams and tie-columns. Since the beam-to-column connections can be subjected to significant shear stresses as the shear force transfers from the beam to the wall, the tie spacing in both the tie-beams and the tie-columns should be reduced at these connections. The transverse reinforcement should be closed ties with 135 degree hooks that are staggered so that they do not all occur at the same corner of the tie-beam or tie-column.

The tie-beams and tie-columns are formed with formwork (usually wood) prior to the concrete placement. One common custom is to size the tie-columns to be the same size as the masonry wall thickness, since this allows the column formwork to be placed directly up against the masonry.

The concrete can be mixed either with a mixer or by hand. Although concrete mixed with a mixer generally produces stronger concrete, mixing by hand can produce adequate concrete provided that quality control procedures are exercised. Concrete placement is usually done by hand using buckets and wheelbarrows. Consolidation is critical for these members since their small size makes them susceptible to voids and rock pockets forming. This is a particular concern for tie-columns with toothing joints where the concrete poured from the top of the wall has to fill each joint. Thus the use of vibrators or tamping rods is highly recommended.

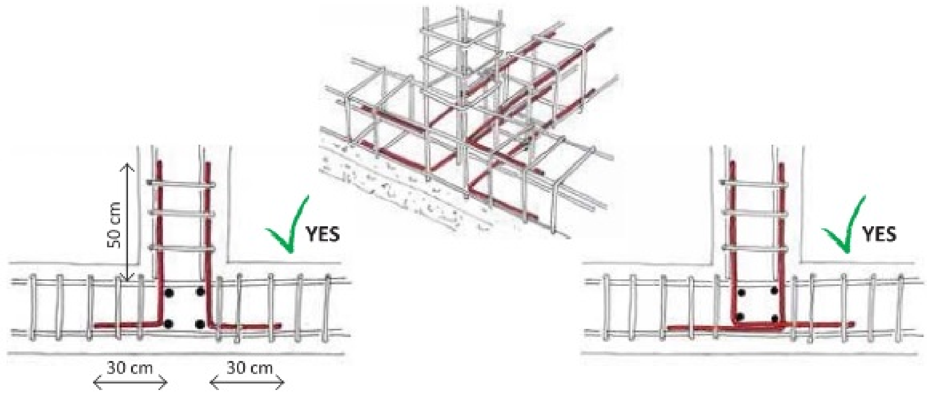


Fig. 3 – Recommended beam to beam connections [6]

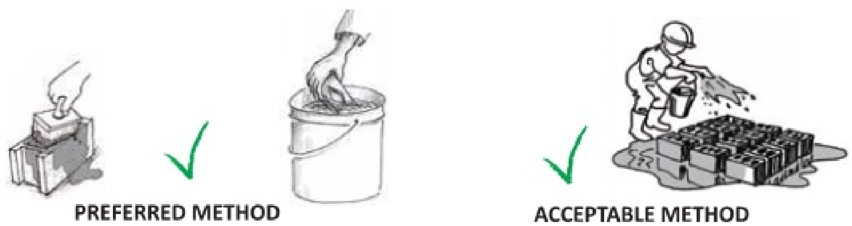
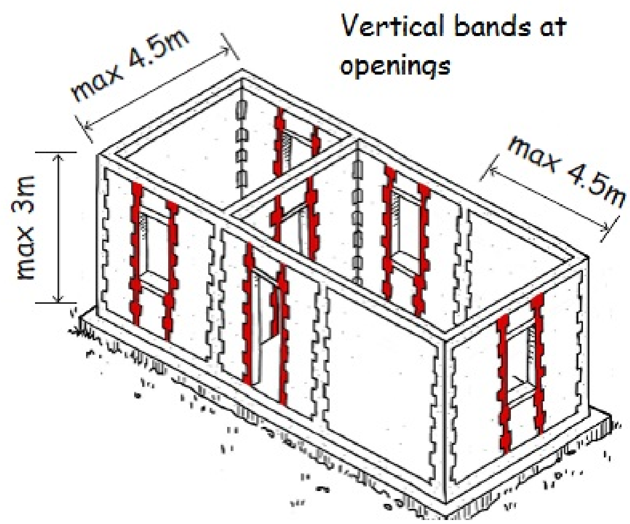


Fig. 4 - Wetting the masonry units prior to installation [6]

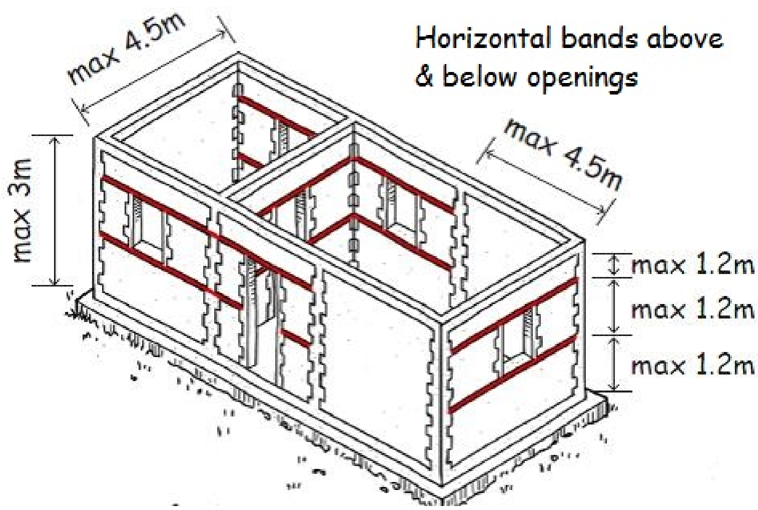
4. Guidebook for Building Earthquake-Resistant Houses in Confined Masonry

The guidebook [12] was originally developed by the Competence Center for Reconstruction of the Swiss Agency for Development and Cooperation (SDC) after the devastating January 2010 Haiti earthquake, and it was adapted for global use with the assistance the Earthquake Engineering Research Institute through the Confined Masonry Network. It was developed as a resource for the mason training program related to confined masonry construction practice in Haiti, which was launched as a response to the urgent need to establish an earthquake-resistant construction practice there. Its main purpose is to improve construction practices in areas where housing construction occurs without technical input, and is intended for use by builders and technicians with limited technical background.

It is a simple and predominantly graphical publication which provides covers the topics such as site selection in hazard-prone areas, building configuration, and the construction of all relevant structural components, including the foundations, walls, and floor/roof. The construction of masonry walls and reinforced concrete confining elements is particularly well covered (Chapters 10 and 11). In addition to reinforced concrete tie-beams provided at the floor and roof level, it is recommended to provide additional horizontal reinforcement in the form of bands at the lintel and sill levels of a building, as illustrated in Fig. 5. This seismic provision is used for nominally reinforced masonry construction in India and some other Asian countries and was also practiced in Haiti after the 2010 earthquake. The purpose is to enhance the in-plane and out-of-plane resistance of walls with openings, which are particularly vulnerable to seismic effects. Detailing of steel reinforcement, often critical for achieving the satisfactory seismic performance, is illustrated in detail in Chapter 6 of the publication. One of the key deficiencies in any masonry construction, including the confined masonry, is related to inadequate strength of masonry materials. The recommendations related to the selection of good quality bricks and blocks are presented in Chapter 9. The guidebook also provides an advice related to construction of floor slabs and roofs (Chapters 12 and 13).



a)



b)

Fig. 5 – Reinforcement in confined masonry buildings: a) vertical RC ties, and b) horizontal RC bands [12].

5. Design Guidelines for Engineered Confined Masonry Buildings

A number of countries have building standards that include provisions for confined masonry, including Mexico, Peru, Chile, and the European Union among others. There are other countries, for example Haiti and Indonesia, where confined masonry is a common method of construction but the standards do not include provisions for it. Because of differences in construction practices, seismic hazards, and other factors, it can be a significant challenge to adopt the building standards from one country for use in another country where such provisions do not exist.

During the development of the guidelines for seismic design of non-engineered confined masonry buildings, the development team determined that there should be a separate guideline document for the engineered design of confined masonry buildings that could not be designed using the prescriptive recommendations of the Guide or per the building standards adopted by region where the buildings would be constructed. A new team of international experts was assembled in 2013 and is currently developing this document. The intent of these guidelines is to provide recommendations for the design of confined masonry buildings that require a detailed engineered design instead of a prescriptive approach, including buildings three stories and taller as well as buildings with irregular configurations.

5.1 Key Topics and Challenges

The topics proposed for the engineering guidelines include ductility, analysis methodology, and design for in-plane and out-of-plane seismic effects.

5.1.1 Ductility

A confined masonry wall consists of an unreinforced masonry wall surrounded by reinforced concrete confining elements that resemble a RC concrete frame but are designed and detailed to achieve pin connections as opposed to rigid connections characteristic of RC frames. Riahi, Elwood, and Alcocer [13] developed a backbone curve for confined masonry walls using the results from 102 monotonic and reversed-cyclic tests collected from several countries and found that the tests demonstrated significant ductility of confined masonry walls in the post-cracking stage. Numerous research studies, including shaking table testing of building models, have been performed in Mexico [14], Peru [15], and Slovenia [16], to evaluate seismic performance of confined masonry structures.

A response reduction factor, R, is used in building codes to quantify the ability of a structural component to dissipate earthquake energy and perform in a ductile manner. Structures made of brittle materials, such as unreinforced masonry buildings, are characterized by a low response reduction factor. Likewise, structures made of ductile materials, such as steel frames, have relatively high R-factors. Building codes in countries where confined masonry has been practiced, such as Mexico [5], specify R-factors for confined masonry buildings. However, there are many building codes that do not include an R-factor specifically for confined masonry walls, in some cases because confined masonry construction is not a common practice. In the absence of code guidance, engineers in some countries use conservative R-factor values for confined masonry, e.g. the same value as for unreinforced masonry. However, because confined masonry walls have proven to be much more ductile than unreinforced masonry, using its R-value would be highly conservative. The authors of the guide are working on determining an appropriate R-factor for confined masonry buildings based on the provisions of several building codes and the methodology proposed in FEMA P695 [17], as discussed by Goddell and Laberenne [18].

5.1.2 Analysis Methods and Modeling

For buildings without structural irregularities the linear static analysis methods specified in most building codes can be successfully used for confined masonry buildings. Irregular confined masonry structures that require a dynamic and/or a non-linear analysis, however, present a significant challenge because of the difficulties in creating analysis models that accurately reflect the behavior of confined masonry walls. Much of this difficulty comes from the fact that confined masonry walls are not homogeneous, but rather consist of several different discrete elements including bricks, mortar, concrete, and reinforcing steel. A successful model would need to be able to tie all of these elements together so that the wall behaves as one element. It would also need to account for the limitations of individual materials and the behavioral characteristics of the connections, in particular the masonry to concrete connections and the tie-beam to tie-column connections. In addition, a successful model would also need to accurately tie in the floor and foundation elements to the wall elements.

A significant portion of the guideline will be devoted to the recommendations for modeling confined masonry structures at different complexity levels, ranging from the Wide Column model used for analysis of confined masonry buildings in countries like Mexico [19] to micro- and meso-models which have been recently developed and validated with results from experimental studies [20].

5.1.3 Design of Confined Masonry Wall Panels for In-Plane Seismic Effects

Appendix C of the *Seismic Design Guide for Low-Rise Confined Masonry Buildings* [3] includes a comparison of some of the confined masonry provisions specified in various municipal and national building codes. This comparison includes the provisions for determining the in-plane shear capacity of confined masonry walls. There are some similarities between the different provisions. For example, most codes factor in a percentage of the axial compression stress on the wall into the shear capacity. The factors range between 0.12 and 0.33 times the axial stress. There are also some significant differences in these provisions. For example, there are codes that account for the shear capacity of the tie-columns in the wall shear capacity equation, whereas other codes specifically exclude it. Some provisions are specific to individual codes. For example, the Peruvian code [21] specifies different shear capacities for different masonry unit types and includes an in-plane slenderness reduction factor. The Algerian code [22] specifically requires a strut-and-tie design. The authors of the guide will conduct a comparison of different provisions for shear capacity to develop a recommended generic in-plane shear capacity equation for use in countries where the building codes do not contain such provisions.

In-plane overturning of confined masonry walls is typically addressed by either limiting the wall aspect ratio or by assuming that the overturning forces are resisted entirely by a force couple in the tie-columns. These simplified methods are usually sufficient for most cases, especially since typical confined masonry construction uses heavy concrete floor slabs that restrict the development of uplift in the walls.

5.1.4 Design of Confined Masonry Wall Panels for Out-of-Plane Seismic Effects

Most building codes address out-of-plane wall stability considerations by restricting the height/thickness ratio of the wall. However, the performance of slender confined masonry walls in recent earthquakes in Indonesia [23, 24] suggests that even walls with height/thickness ratios as high as 30 were able to resist out-of-plane seismic effects without collapse. Findings of an experimental study involving full-scale shaking table testing of a typical Indonesian confined masonry building [25] pointed to similar conclusions. The factors that determine the out-of-plane performance of confined masonry walls in general and the walls in Indonesia in particular are not fully understood due to limited research evidence. Some of the factors that could play a role include arching action, the length-to-thickness ratio as well as the height-to-thickness ratio, and the stiffness of the tie-columns and tie-beams. Research studies on out-of-plane behavior of confined masonry wall panels from Mexico [26] and India [27] may lead to the development of rational design criteria for confined masonry walls subjected to out-of-plane seismic effects that could be used in countries such as Indonesia where wall height/thickness restrictions are not practical.

6. Conclusions

This paper outlines development and key recommendations of design and construction guidelines for confined masonry buildings in regions of moderate to high seismic hazard. It is expected that these guidelines will be used primarily in countries where confined masonry construction is not addressed by building codes. The guideline for non-engineered confined masonry buildings recommends prescriptive design provisions for low-rise buildings related to the wall layout and density, and prescribes minimum size requirements for structural components of confined masonry buildings, reinforcement size and detailing. The guide also includes a summary of the seismic design provisions for confined masonry buildings from relevant international codes.

Two construction guidelines for confined masonry buildings have been developed, one whose primary audience is building design professionals and trained craftsmen and one whose primary audience is untrained workers. These documents draw from existing construction guidelines to develop recommendations for constructing confined masonry buildings, including recommendations for wall layout and configuration, materials, workmanship, and quality control.

A guideline for engineered confined masonry buildings is currently in development. This document will provide guidance on the engineered design of confined masonry structures, including recommendations for consideration of ductility, analysis and modeling methods, and design for in-plane and out-of-plane seismic effects.

7. Acknowledgements

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