CHAPTER (1)
INTRODUCTION

1.1 General

Confined masonry (CM) is considered one of the popular forms of low-cost, low-rise constructions throughout the world; including Mexico, South and Central America, South-East Asia, Middle East, and South-Eastern Europe. The system relies on a load-bearing wall encased by small cast-in-place reinforced concrete tie columns and tie beamsThe distinguishing feature of confined masonry construction is that the masonry wall is constructed prior to the casting of the confining elements, tie columns and tie beams, thus both elements respond integrally when subjected to lateral loads. In general, tie columns have a rectangular section whose dimensions typically correspond to the wall thickness. For tie beams, both wall thickness and floor type influences the choice of the dimensions. The confining elements are intended to confine the masonry panel preventing disintegration, to enhance wall deformation capacity, and connectivity with other walls and floor diaphragms. The recent European codes states that the contribution of vertical confinement to vertical and lateral resistance should be ignored. The amount of reinforcement is determined empirically on the basis of experience, and depends on the height and size of the building.

In a way, the behaviour is similar to that of infilled reinforced concrete frames. However, in the case of confined masonry, tie-columns do not represent the load-bearing part of a structure. The in-plane response of a confined masonry wall is distinctly different from that of reinforced concrete infilled frames, where the frame is constructed prior to the masonry infill. Although a confined masonry wall experiences both flexural and shearing deformations, the masonry infill deforms in a shear mode within a frame that attempts to deform in flexural mode, resulting in separation of the frame and infill wall along the tension diagonal.

If properly constructed, confined masonry construction is expected to show satisfactory performance in earthquakes. The bad experience with this form of construction in past earthquakes involved structures that were built without tie columns and/or tie beams, with inadequate roof-to-wall connection, or with poor-quality materials and construction. The main observed damage patterns can be summarized as: 1) Shear cracks in walls that propagate into the tie-columns; most cracks passed through mortar joints, 2) Crushing of masonry units has been observed in the middle portion of the walls subjected to maximum stresses, 3) Horizontal cracks at the joints between masonry walls and reinforced concrete floors or foundations, 4) Cracks in window piers and walls due to out-of-plane action in inadequately braced walls, 5) Crushing of concrete at the joints between vertical tie-columns and horizontal tie beams when the reinforcement was not properly anchored.

Since 2010, an extensive research program, aiming at developing structurally and economically efficient hybrid building system for developing countries in general and for Egypt in particular, is being undertaken at the Department of Structural Engineering of Ain Shams University. This thesis aims studying the lateral load behaviour of confined masonry walls with openings and built using locally available materials and with common workmanship and construction practices.

1.2 Objectives

The main objective of this investigation is to examine the Lateral load behavior of confined masonry walls with openings.The various specific objectives are:

1- Evaluation of lateral load resistance and behavior of confined clay masonry walls with openings.
2- Development and validation of numerical models to simulate the response of the confined masonry walls.
3- Evaluation of untested design configurations using the validated models.

1.3 Scope

An experimental program and an analytical study were designed to achieve aforementioned objectives:

<u>Experimental Investigation:</u>

The experimental program evaluated the structural behavior of confined masonry walls with opening under lateral loads. Four near full-scale wall panels, three CM walls comprising a brick wall, two confining columns and a bond beam, and one wall by in filled system were statically tested under constant vertical load and monotonically increasing lateral load up to failure. Three CM wall panels had various configurations, type of openings and size.

Analytical Modeling:

A numerical study will be conducted using the finite element method to simulate the behavior of the tested walls. The models well validated in light of the experimental results. The calibrated models were used to conduct a parametric study on untested conditions of wall opening size, location, axial stresses and different aspect ratios. The results of both phases of the research, experimental and analytical, were used to propose a set of design guidelines for confined masonry walls with openings.

1.4 Thesis Layout

In addition to this introductory chapter, this thesis includes:

Chapter (2): Literature Review

This chapter presents a literature review of confined masonry building, System describtion, Comparison between confined masonry structures and in filled masonry structures, Damage pattern and overall seismic behavior, the parameters effect on shear capacity of CM walls , Lateral Load capacity and Objective of the experimental program.

Chapter (3): Experimental Program

This chapter describes the experimental program conducted at the Reinforced Concrete Laboratory of Faculty of Engineering at Ain Shams University to four full scale wall specimens.Three CM walls and one wall specimen by infilled construction system were tested to failure.The CM walls were solid,with window and door opening.The infilled wall specimen was solid.

Chapter (4): Experimental Results

This chapter describes the experimental results and the experimental investigation conducted at the Reinforced Concrete Laboratory of Faculty of Engineering at Ain Shams University to four full scale walls specimens (infilled and confined specimens).

Chapter (5): Finite Element Analysis and Extension

This chapter presents the finite element (FE) analysis used to simulate the behavior of the tested confined masonry walls and a comparison between the results of the FE models and the experimental results was made to verify the FE-analysis. A parametric study was conducted to simulate the response of untested design configurations and propose set of design guidelines for design.

Chapter (6): Conclusions and Recommendations.

A summary of the work conducted in this thesis is presented. Several conclusions are introduced to give an understanding of the lateral load behavior of confined masonry with openings and the recommendations for future work.

Appendix (A) : An Illustrated Guide for Construction.

This the final part for thesis presents an illustrated guide for construction of buildings by CM system.

CHAPTER (2)

LITERATURE REVIEW

2.1 General

Confined masonry (CM), as an effective structural system for low- and medium-rise dwellings and apartment buildings up to five stories, is widely used in central and south America, central and south Asia, and eastern and southern Europe.

The use of masonry walls confined with slender vertical (tie column) and horizontal (bond beam) elements along their borders can be traced back to the beginning of the last century. CM walls, in fact, have been first utilized for the reconstruction of some Italian cities flattened in such seismic events as the 1908 Messina earthquake (Murty et al, 2006), and the earthquake of July 23-1930 (Freeman, 1932). Holding the walls together and in joint with other structural components, providing some out-of-plane seismic resistance, and introducing some level of ductility to unreinforced masonry (URM) walls were among the main objectives of panel confinement.

As an alternative to URM and adobe buildings, CM has overcome many seismic deficiencies to which the two latter systems were highly vulnerable. However, material properties, workmanship and construction sequence together with maintenance quality are among the key construction factors that can significantly affect the seismic performance of this class of structural walls; and therefore, aside from structural considerations, should receive due attention.

Demonstration of its superior seismic performance in successive moderate and severe earthquakes, as is evident from (Figure 2.1), has led to a steady increase in the application of CM walls. This improvement has been achieved at only marginally higher cost, thereby giving this structural system an economic feasibility. Furthermore, taking advantage of the available materials and previous construction practice, to which the local developers are familiar, also have accommodated considerably the dissemination of this structural system

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Figure 2.1: (a) A completely demolished URM dwelling, (b) An intact CM building, 2003 Bam earthquake, Iran (Eshghi and Naserasadi,2005)

Although the details of CM walls have tended to be developed over time based on local customary construction practices, with design and construction therefore to some extent empirical, experimental and analytical studies together with damage observations have effectively contributed to a comprehensive understanding of their seismic behavior in terms of dominant failure modes and damage patterns, and have shown how some of the seismic deficiencies to which these load bearing walls are vulnerable can be overcome. Damage pattern and overall seismic behavior, masonry unit and mortar properties, openings, panel reinforcement, and the effects of such factors as axial stress and panel aspect ratio are amongst the most frequent topics investigated in analytical studies, laboratory tests, and field observations. These topics, together with existing models for prediction of seismic performance of CM walls, are described in detail throughout this chapter.

2.2 System Description

The system relies on a load-bearing wall surrounded by small cast-in-place reinforced concrete tie columns and bond beams. The distinguishing feature of confined masonry construction is that the masonry wall is constructed prior to the casting of tie columns and bond beams, thus both elements respond integrally when subjected to lateral loads. In general, tie columns have a square section whose dimensions typically correspond to the wall thickness. For bond beams, both wall thickness and floor type influences the choice of the dimensions. The confining elements are intended to confine the masonry panel preventing disintegration, to enhance wall deformation capacity, and connectivity with other walls and floor diaphragms. The requirement of recent European codes the contribution of vertical confinement to vertical and lateral resistance should be ignored. The amount of reinforcement is determined arbitrarily on the basis of experience, and depends on the height and size of the building. Figure (2.2), shows the component of confined masonry system.

In a way, the behavior is similar to that of reinforced concrete frames with masonry in filled. However, in the case of confined masonry, tie-columns do not represent the load-bearing part of a structure. The in-plane response of a confined masonry wall is distinctly different from that of reinforced concrete in filled frames, where the frame is constructed prior to the masonry infill. The frame is constructed prior to the masonry infill. (Figure 2.3), shows the different of the construction sequence between confined masonry and in filled frames.

Although a confined masonry wall experiences both flexural and shearing deformations, the masonry infill deforms in a shear mode within a frame that attempts to deform in flexure, resulting in separation of the frame and infill wall along the tension diagonal.

If properly constructed, confined masonry construction is expected to show satisfactory performance in earthquakes.

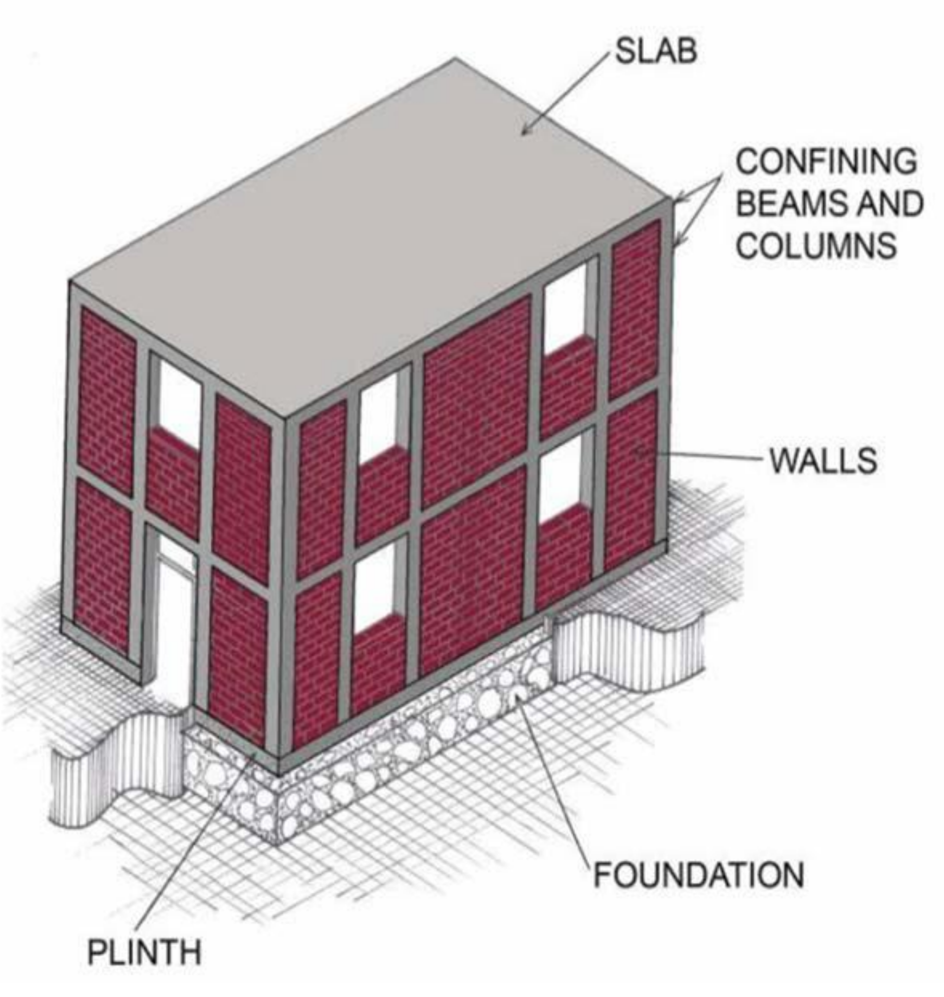

Figure 2.2: Main elements of confined masonry system (Blondet, 2005)

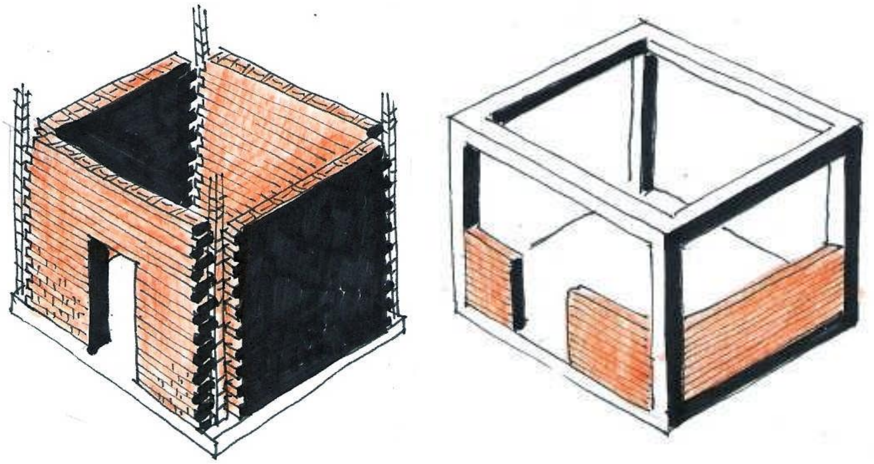

Figure 2.3: difference between confined masonry system and reinforced concrete frames with masonry in filled, (Sdc, 2007).

2.3 Damage Pattern and Overall Seismic Behavior

Despite the presence of stiffness decay due to the formation of flexural cracks along the height of tie columns and micro cracks that exist in masonry units, in elastic range and at the early stages of loading, CM walls may still be approximated as elastic shear beams whose stiffness is provided by both panel and confining elements (Yañez et al, 2004; Alcocer et al, 2004; Irimies, 2000; Gibu and Zavala, 2002). At this stage, as experimental results indicate, strain in tie-column longitudinal reinforcement changes alternately from positive to negative, implying the monolithic behavior of CM walls (Tomazovic and Klemenc, 1997(a), Zavala et al, 1998).

Onset of inclined shear cracks in the middle of solid panels and their extension towards tie columns result in further decrease in the stiffness of the panel. The time at which the first major crack forms usually coincides with a substantial detectable decline in effective stiffness. These cracks usually pass through mortar joints in a zig-zag pattern (Marinilli and Castilla, 2004; Yañez et al, 2004; Irimies, 2002).

Post-cracking behavior of typical CM walls, whose response is mainly governed by shear deformations, is directly influenced by friction, brick interlock, and shear resistance of tie column ends (Flores and Alcocer, 1996). As is shown in (Figure 2.4), at this stage, the cracked wall pushes tie columns sideways, and produces permanent tension in them (Tomazevic and Klemenc, 1997(a); Zavala et al, 1998). The masonry panel, in turn, would be under the effect of more compressive stresses, provided that an adequate bond allows sufficient load transfer between wall and confining elements.

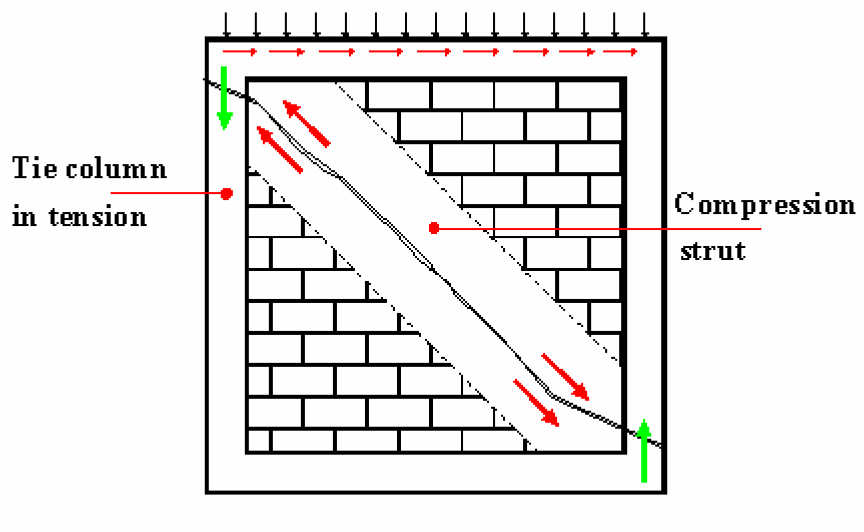

Figure 2.4: Illustration of the seismic behavior beyond cracking limit state

Confinement, in fact, alters the failure mode of URM walls and slows down the rate at which stiffness would decay, therefore improving the post-cracking seismic performance of CM walls. Peak point of the recorded response which defines the maximum load state is usually sustained at the extension of cracks into tie columns ends. To prevent these cracks from opening up considerably, it is recommended to restrain the drift capacity of CM walls to some reasonable degree (Alcocer, 1996). This limit, however, is under the direct influence of panel and confining elements characteristics, and therefore should be determined for each wall appropriately.

As shown in (Figure 2.5), post-peak behavior of CM walls is significantly influenced by reinforcement detailing of tie columns ends. Formation of vertical cracks at wall-column interface, and partial separation of these elements (Zabala et al, 2004; Ishibashi et al,1992), and penetration of cracks into masonry units (Tomazevic and Klemenc, 1997(a)) at large deformation levels is usually followed by masonry crushing in the middle of the panel, extensive concrete cracking and crushing, and longitudinal rebar rupture/buckling at tie column critical end zones (Alcocer et al, 2004; Tomazevic and Klemenc, 1997(a)). Stiffness of the panel at large deformation levels is mainly provided by confining elements which act to slow the rate of stiffness degradation (Ishibashi et al, 1992). The residual stiffness of a CM wall is about 20% of its initial stiffness at 20% strength loss from the maximum measured shear (Alcocer et al, 2004).

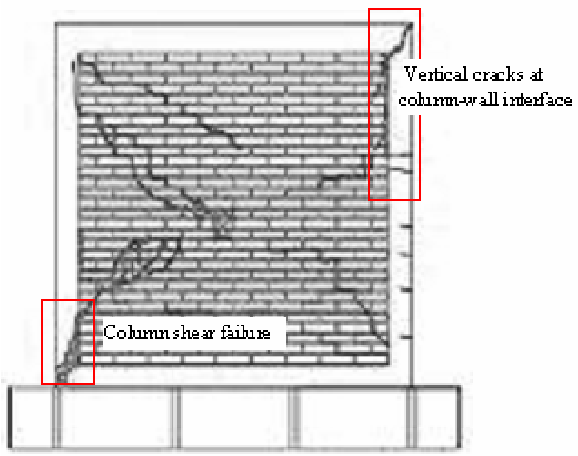

Figure 2.5: Post-peak behavior of a typical CM wall (Zabala, 2004)

For multi-story CM walls, experimental results and aftermath of earthquakes (Figure 2.6) suggest, damage mainly concentrates in the first story, and in the direction of motion. This damage concentration leads to the softening action of first story panels which may be ascribed to the larger-than-unity shear span ratios that these walls usually have, and is confirmed by close match of the first story response curves of such multi-story walls with the seismic response of an isolated CM wall. Dissipation of almost all energy in the critical first story further stresses the leading role of proper confinement of these CM walls (Irimies, 2002; Alcocer et al, 2004; Tomazevic and Klemenc, 1997(b)).

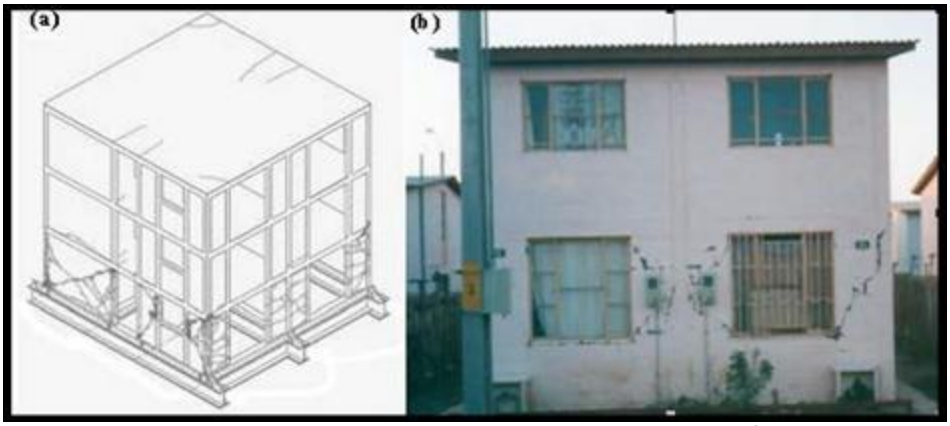

Figure 2.6: CM house with damage concentration in the first story(a) Alcocer et al,2004 (b) 1997 Punitaqui earthquake, Chile (Gomez et al, 2002)

Such characteristics as low tie column longitudinal reinforcement and high panel aspect ratio, however, may lead to the predominance of flexural deformations. When seismic behavior of CM walls is governed by flexural deformations, as is shown in (Figure 2.7) horizontal bending cracks at lower courses of the panel may extend into tie columns ends and shear them off at large deformation levels (Zabalaetal2004).

This further emphasizes the vital role of tie column ends shear resistance in the overall seismic behavior of CM walls.

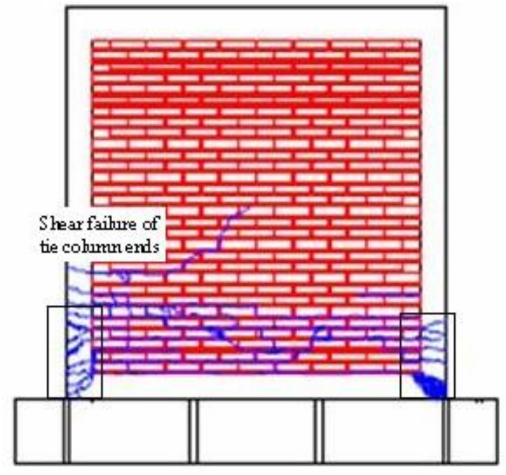

Figure 2.7: Flexural failure and penetration of cracks into tie columns ends (Zabala et al, 2004)

2.4 Parametric effects on the Performance of confined masonry under lateral loads

2.4.1 Openings

Experimental tests and damage observations indicate that shear cracks usually initiate at opening corners and extend towards the middle of piers. Size, shape, location and confinement detailing of openings have a great impact on the seismic performance of CM walls. This behavior is in fact highly correlated to the inclination of the diagonal struts forming either side of the openings, and the shear capacity of tie columns that are utilized to border them (Yañez, et al, 2004).

Opening size and the degree of coupling affect both initial stiffness and cracking pattern. The rate at which stiffness degrades, however, is almost independent of these factors (Ishibashi et al, 1992). While excessively large openings could reduce shear capacity of CM walls by almost 50% (Gostic and Zarnic, 1999), their effect on seismic performance is almost negligible when size is restrained to approximately 10% of the wall gross area (Yañez, et al, 2004). Furthermore, symmetrical distribution of openings and utilizing a spandrel below them are among key factors that can alleviate the harmful effects of openings (UNIDO/ UNDP, 1984; Alcocer et al, 2003; Yañez, et al, 2004).

Opening confinement is also substantially beneficial in preventing the instability of heavily damaged triangular portions besides the openings that can fall out under relatively high axial stresses (Flores et al, 2004). Opening confinement, as is illustrated in (Figure 2.8) improves post-cracking deformation and shear capacities of CM walls, and introduces more stability to the response curves. Tie columns at opening extremes help the integral action of the panel and are recommended to be provided with tightly spaced stirrups at the corners of the openings. This will arrest extensive concrete cracking and crushing at opening corners until large deformation levels, thus improving the seismic response of the panel (Flores et al, 2004; Ishibashi et al, 1992; Alcocer et al, 2003).