Confined Masonry Buildings: Construction Practice and Seismic Design Concepts

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EARTHQUAKES HAPPEN

...and they can be very destructive
Recent Deadly Earthquakes in the World

➢ 1993 Latur, Maharashtra, India – 8000 deaths
➢ 1999 Ducze, Turkey – 20000 deaths
➢ 2001 Bhuj, Gujarat, India – 14000 deaths
➢ 2003 Boumerdes, Algeria – 3000 deaths
➢ 2004 The Great Sumatra Earthquake and Tsunami in Indonesia, Thailand, Sri Lanka, and India - 270,000 deaths
➢ 2005 Kashmir Earthquake in Pakistan and India - 100000 deaths
CONFINED MASONRY:
an opportunity for improved seismic performance both for unreinforced masonry and reinforced concrete frame construction in low- and medium-rise buildings
Confined Masonry Construction: An Alternative to Reinforced Concrete Frame Construction

An example from Chile (Source: Ofelia Moroni)
Confined Masonry Construction: An Alternative to Unreinforced Masonry Construction

An example from Indonesia (Source: C. Meisl, EERI)
Earthquake Performance

Confined masonry construction has been practiced in countries/regions with very high seismic risk, such as

- Latin America (Mexico, Chile, Peru, Argentina),
- Mediterranean Europe (Italy, Slovenia),
- South Asia (Indonesia),
- Middle East (Iran) and
- the Far East (China).
Earthquake Performance (cont’d)

Confined masonry construction has been exposed to several destructive earthquakes:

- 1985 Lloleo, Chile (magnitude 7.8)
- 1985 Mexico City, Mexico (magnitude 8.0)
- 2001 El Salvador (magnitude 7.7)
- 2003 Tecoman, Mexico (magnitude 7.6)
- 2007 Pisco, Peru (magnitude 8.0)
- 2003 Bam, Iran (magnitude 6.6)
- 2004 The Great Sumatra Earthquake and Tsunami, Indonesia (magnitude 9.0)
- 2007 Pisco, Peru (magnitude 8.0)
- 2010 Maule, Chile (magnitude 8.8)

Confined masonry buildings performed very well in these major earthquakes – some buildings were damaged, but no human losses
Confined Masonry and RC Frame Construction: Performance in Recent Earthquakes

January 2010, Haiti
- M 7.0
- 300,000 deaths

February 2010, Chile
- M 8.8
- 521 deaths
  (10 due to confined masonry construction)
Confined Masonry Construction: a Definition

Confined masonry is a construction system where the walls are built first, and RC columns and beams are cast afterwards.
A difference between the confined masonry and reinforced concrete frames = construction sequence

**Confined Masonry**
- Walls first
- Concrete later

**Reinforced Concrete Frame**
- Concrete first
- Walls later

*Source: Tom Schacher*
Reinforced Concrete Frame Construction
Confined Masonry Construction
Key Components of a Confined Masonry Building

Key structural components of a confined masonry building are:

- **Masonry walls** made either of clay brick or concrete block units
- **Tie-columns** = vertical RC confining elements which resemble columns in reinforced concrete frame construction.
- **Tie-beams** = horizontal RC confining elements which resemble beams in reinforced concrete frame construction.
Components of a Confined Masonry Building
Confined Masonry: Construction Practice
An example from Chile
Confined Masonry Under Construction in Earthquake-Prone Regions of the World

Indonesia

Mexico

Pakistan

Peru
Location of Confining Elements is Very Important!

tie-columns at wall ends and intersections

tie-columns at openings

thickness $\geq 120$ mm

tie-column spacing $\leq 4$ m

door

window
Location of Confining Elements is Very Important!

- tie-beam in parapets ≥ 500 mm
- tie-columns in parapets
- tie-beam spacing
- slabs
- tie-columns at wall intersections
- confining elements around openings

Constraints:
- \( \frac{H}{t} \leq 25 \)
- \( t \geq 120 \text{ mm} \)

Notes:
- Tie-column spacing:
  - 6.0 m (moderate seismicity)
  - 4.5 m (high seismicity)
Wall Density

- A key parameter influencing the seismic performance of confined masonry buildings - confined masonry buildings with adequate wall density were able to sustain the effects of major earthquakes without collapse.

- Wall density index ($d$) is a ratio of the total wall area in each orthogonal direction and the floor plan area.

- The required $d$ value depends on seismic hazard, soil type, number of stories, building weight, and masonry shear strength.
How to Determine Wall Density?

\[ d = \frac{A_w}{A_p} \]
**Recommended Wall Density**

The Guide recommends $d$ values from $1$ to $9.5\%$.
How to Distribute Seismic Forces to Walls?

Wall i
(area $A_i$)

$V_i = \text{Total seismic force at a floor level}$
Seismic Force Distribution

\[ V_i = V \cdot \frac{F_i A_i}{\sum_{i=1}^{N} F_i A_i} \]

\[ F = 1 \]
if \( H/L \leq 1.33 \)

OR

\[ F = (1.33 \frac{L}{h})^2 \]
if \( H/L > 1.33 \)

This is based on the Mexican Code NTC-M 2004
Mechanism of Seismic Response in a Confined Masonry Building

Masonry walls

Critical region

Diagonal cracking

Source: M. Astroza lecture notes, 2010
Mechanism of Seismic Response in a Confined Masonry Building

Onset of Diagonal cracking

Damage in critical regions

Masonry walls
Seismic Design Objectives

➢ RC confining elements must be designed to prevent crack propagation from masonry walls into critical regions of confining elements.

➢ This can be achieved if critical regions of the RC tie-columns are designed to resist the loads corresponding to the onset of diagonal cracking in masonry walls.
This seismic performance should be avoided!
Seismic Design of Confined Masonry Components = Wall + RC Confining Elements

Wall + RC confining elements = Wall = shear due to V + Confining elements = tension/compression due to M
Seismic Design of Walls for Shear

Use CSA S304.1
Cl.10.10.1.1

$V_r = V_m$

Consider masonry shear resistance only

Diagonal crack is caused by shear stresses (same as beams)!

See page 2-11 of Seismic Masonry Guide (Anderson and Brzev)
Design Walls for Shear

2.3.2.1 Flexural shear walls

Flexural shear walls are characterized by height/length aspect ratio of 1.0 or higher (see Figure 2-6a). Consider a reinforced masonry shear wall built in running bond which is subjected to the effect of factored shear force, \( V_f \), and the factored bending moment, \( M_f \).

Factored in-plane shear resistance, \( V_r \), is determined as the sum of contributions from masonry, \( V_m \), and steel, \( V_s \), that is,

\[
V_r = V_m + V_s \quad (1)
\]

Masonry shear resistance, \( V_m \), is equal to:

\[
V_m = \phi_m (v_m b_w d_v + 0.25 P_d) \gamma_g \quad (2)
\]

Wall dimensions \((b_w \text{ and } d_v)\):
- \(b_w = t\) overall wall thickness (mm) (referred to as "web width" in CSA S304.1); note that \( b_w \) does not include flanges in the intersection walls
- \(d_v\) = effective wall depth (mm)
- \(d_v \geq 0.8b_w\) for walls with flexural reinforcement distributed along the length

Wall cross-sectional dimensions \((b_w \text{ and } d_v)\) used for shear design calculations are illustrated in Figure 2-10.
In-plane shear failure: hollow clay block masonry
In-plane shear failure of masonry walls at the base level - hollow clay blocks (Cauquenes)
In-plane shear failure of masonry walls at the base level (cont’d)
Design of RC Confining Elements

Find $T$ and $C$ forces due to $M$ and design according to CSA A23.3 concrete code (same as RC columns)

$$M_r = 0.9 A_s \phi_s F_y d_1$$

As = total steel area in a tie-column

$A_s$ = total steel area in a tie
Tie-Column Failure
Buckling of a RC Tie-Column due to the Toe Crushing of the Masonry Wall Panel
How to prevent buckling and failure of RC tie-columns?

➢ All surveyed buildings in Chile had uniform tie spacing 200 mm
➢ Tie size 6 mm typical, in some cases 4.2 mm (when prefabricated cages were used)

Closer tie spacing at the ends of tie-columns (200 mm regular and 100 mm at ends)
How to prevent buckling failure of RC tie-columns?

- Tie spacing \((s)\) should not exceed 200 mm - this applies to RC tie-columns and tie-beams
  - For regions of high and very high seismicity, reduced tie spacing \((s/2)\) is required at the ends of tie-columns, as shown in Figure 45 b. The length over which the reduced tie spacing is used should not exceed the larger of the following two values:
    - \(2b\), where \(b\) is the tie-column dimension, or
    - \(h_o/6\), where \(h_o\) is the tie-column clear height.
  - For regions of moderate and low seismicity, an uniform tie spacing \((s)\) of 200 mm should be used throughout - it is not required to reduce tie-spacing at the tie-column ends.

Source: Confined Masonry Guide, Jan 2011 draft
Shear Failure of RC Tie-Columns
How to Prevent Shear Failure?

Column shear capacity should be checked. Shear failure is generally associated with inadequate transverse (shear/confinement) reinforcement.

\[ V_p \geq V_r / 2 \]

\[ V_r = \text{wall shear resistance} \]

Same approach like RC frames with infills!

Source: M. Astroza lecture notes, 2010
Confined Masonry: Construction Details

Good connections are of critical importance!

SOLUTION: Sufficient Anchoring
Inadequate Anchorage of Tie-Beam Reinforcement
Inadequate Anchorage of Tie-Beam Reinforcement
(another example)
Tie-column Vertical Reinf and Tie-Beam Longitudinal Reinforcement

**Figure 42.** Tie-beam construction: a) reinforcement is a must! (Brzev, 2008).

**Figure 43.** Tie-beam reinforcement details: a) confinement reinforcement must be added when prefabricated.
SEISMIC DESIGN GUIDE
FOR LOW-RISE CONFINED MASONRY BUILDINGS

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Draft guide available online at
www.confinedmasonry.org