

DR/DRR Field Guide: Confined Masonry

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Introduction

EMI delivers California Safety Assessment Program (C-SAP) training to prepare disaster responders for post-event building evaluations. Because the standard C-SAP curriculum does not address confined masonry construction, our training includes supplemental instruction on this structural system. This field guide summarizes that training and serves as a field reference for responders deployed to regions where confined masonry buildings are common.

The guide provides an overview of confined masonry construction, including its materials, structural components, construction sequence, and expected performance under earthquake and wind loading. It also summarizes common hazards, damage patterns, and key considerations for inspection and post-event safety assessments.

Although confined masonry construction varies by region, the structural principles presented in this guide are broadly applicable and intended to support consistent observations during international disaster response operations.

DISCLAIMER

Readers are expected to possess the education and training necessary to properly apply this information; this Guide is not a substitute for professional expertise.

EMI works in many countries with limited design standards or code enforcement. Therefore, this document follows internationally accepted standards whenever possible. For specific projects, applicable local standards and codes take priority. Follow the latest edition of local standards regardless of any specifications explicitly or implicitly set forth in this document.

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Field Guide

1 Basics

1.1 WHAT IS CONFINED MASONRY?

Confined masonry refers to a common type of wall construction found globally. These walls are typically composed of unreinforced masonry, such as brick, block, or stone, bounded by concrete beams and columns. In some cases, confined masonry walls occur within steel frames, though this is less common. The masonry units are mortared together and bonded to the surrounding frame (see Figure 1).

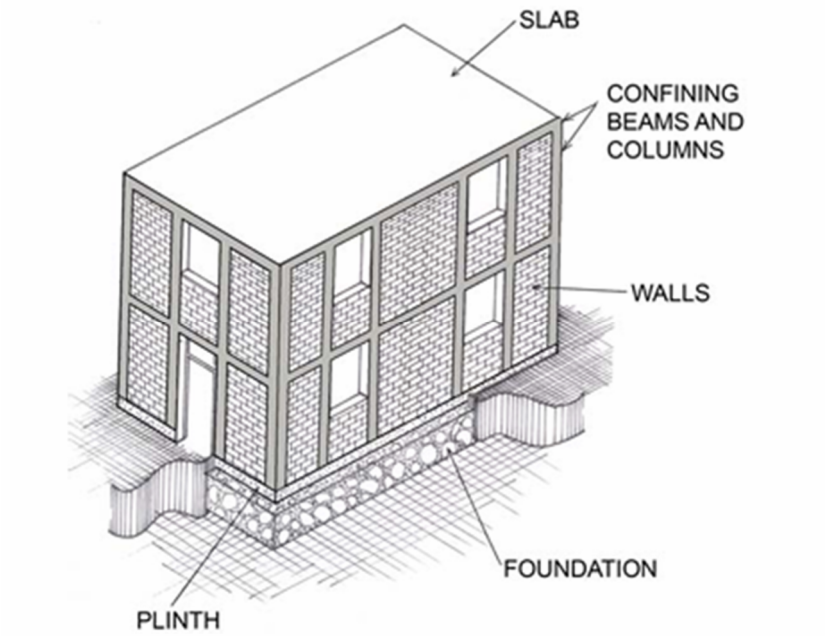


Figure 1: Confined Masonry Components (credit: Blondet, 2005)

While terminology around masonry walls varies across regions, this guide follows the EMI Structural Design Guide and most international references (e.g., Meli et al., Schacher & Hart, Peru's NTE E.070, and Eurocode 6). In "confined masonry" (CM), the masonry walls are built first and the reinforced concrete tie columns and beams are then cast against them, locking wall and frame together. When the concrete frame is built first and the masonry is placed inside it afterwards, the system is a masonry-infilled reinforced concrete frame ("infill frame"). Despite the different names, these are essentially the same system: they use the same materials and builders, behave similarly in low-level shaking, and are often separated only by construction sequence. The enhancements in this guide are small, affordable changes that move traditional construction toward true confined masonry. The two may look alike once plastered but behave differently in severe earthquakes. See Sections 4.1 and 4.5 for more on CM vs. infill frames.

1.2 CONSTRUCTION

CM is built in the following sequence:

1. Foundation
2. Grade beam or plinth.
3. Masonry walls, toothed at tie column locations
4. Concrete tie columns, cast against the masonry
5. Concrete ring beam (with floor or roof slab).
6. Plaster over the wall to finish (optional)

In an infill frame, the order is reversed: the concrete columns and beams are cast first, and the masonry is placed inside the finished frame.

1.3 PERFORMANCE

CM produces a heavy, durable structure that can resist high gravity loads and is resistant to lateral loads from high wind events. However, this construction type is vulnerable to seismic ground shaking. The lateral-load-resisting mechanism of masonry walls, whether confined or infilled, is brittle, or non-ductile, and cannot sustain large drifts. Seismic-load failure can be catastrophic.

1.4 WHY IS IT SO COMMON?

CM construction has several advantages over other types of construction:

1. It is more resilient than unconfined unreinforced, masonry walls.
2. It can be finished nicely with plaster.
3. Concrete and rebar are used sparingly.
4. Small reinforcing steel bars (rebar) are used in the concrete frame.
5. Masonry is locally sourced.
6. Minimal equipment required to construct.
7. Material choices help keep the structure at a lower cost compared to many alternatives.
8. It is perceived as a more durable, longer-lasting structure.

2 Materials

2.1 CONCRETE

The concrete used in CM is typically low strength. Most likely, it is in the range of 7-14 MPa (1,000-2,000 psi) unless there are adequate specifications and inspection. Columns can be as small as 200 x 200 mm (8" x 8"). Concrete is often mixed on the ground or in batches in a stand mixer.

2.2 REBAR

Rebar typically consists of 10 or 12 mm (#3 or #4) verticals in the columns with 6 mm (1/4") ties, sometimes smooth in lieu of deformed bars. Usually 280 MPa (Grade 40 ksi) yield strength is assumed, though 415 MPa (Grade 60 ksi) yield strength is also used.

2.3 MASONRY

This is where the most variation is found. Options include:

- Solid or hollow clay brick or tile
- Hollow concrete block
- Rough Rock or dressed stone.

2.4 MORTAR

Mortar consists of a cement and sand paste. It is used to adhere the infill together and to the concrete frame and to keep the masonry rows level.

2.5 CHARACTERISTICS OF WELL-BUILT CONFINED MASONRY

- Concrete: engineered concrete mix and quality assurance during batching, placement, and curing.
- Rebar: tight tie spacing used (50–75 mm [2"-3"] on centre) at the top and bottom of the columns.
- Masonry: built before the columns and locked into concrete.
- Mortar: quality and strength controlled, with consistent joint thickness maintained.

See *Construction Guide for Low-Rise Confined Masonry Buildings* in Appendices: References for more information.

3 Layout & Foundations

3.1 BUILDING LAYOUT PLAN

A typical CM building begins with a foundation and plinth. Concrete columns and masonry walls are built above the plinth, with concrete floors placed at each level and a final roof at the top. See Section 4 of this guide for more detail on each element.

For preliminary review, note the main layout limits before checking the plan: column spacing should generally not exceed 4.5 m (15 ft) or 6 m (20 ft) depending on regional seismicity; floor-to-floor height should be consistent and should not exceed 3 m (10 ft); and CM buildings should generally be limited to five stories or 13 m (45 ft) tall. A story that is taller or weaker than those above or below can create a soft-story condition that is more susceptible to earthquake damage or collapse.

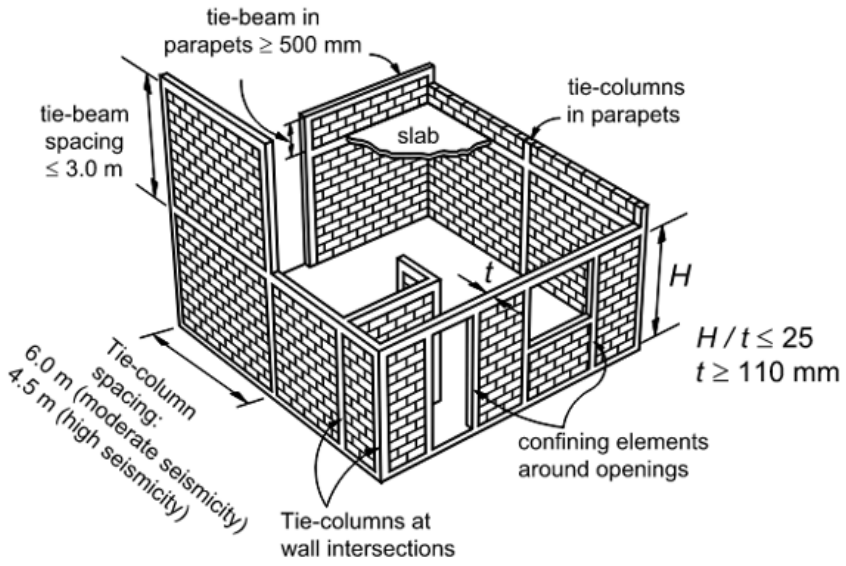


Figure 2: Key recommendations for non-engineered CM buildings (credit: NTC-M, 2004)

A CM building's performance in seismically active regions is related to several wall and plan layout considerations. Things to consider are the location and placement of CM walls, the aspect ratio of the building footprint, plan and elevation irregularities, and alignment of openings.

1. The building plan should be a regular shape. (Figure 3)
2. The aspect ratio of length to width should not exceed 4.0. (Figure 4)
3. Walls should be built in a symmetrical manner, when possible, to reduce torsional effects on the building. (Figure 5)

4. Shear walls should be placed and conform to the Wall Density Method in Section 5.1 as well as being symmetrical across the centre of mass of the building. (Figure 6)
5. Walls should be vertically continuous with no overhangs or offsets. (Figure 7)
6. Openings should be vertically aligned from floor to floor. (Figure 8)

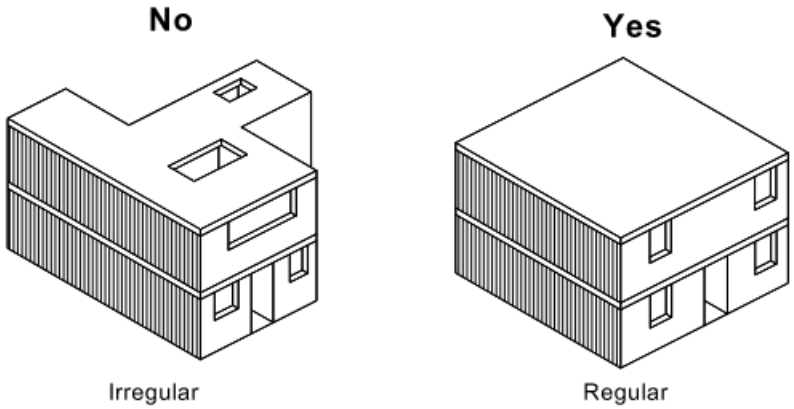


Figure 3: Regular building shape (credit: Seismic Design Guide for Low-Rise Confined Masonry Buildings)

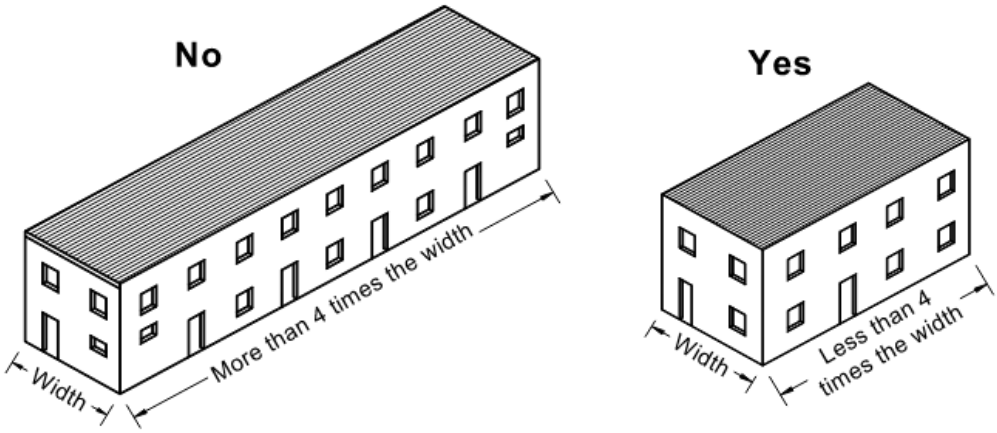


Figure 4: Building length-to-width aspect ratio (credit: Seismic Design Guide for Low-Rise Confined Masonry Buildings)

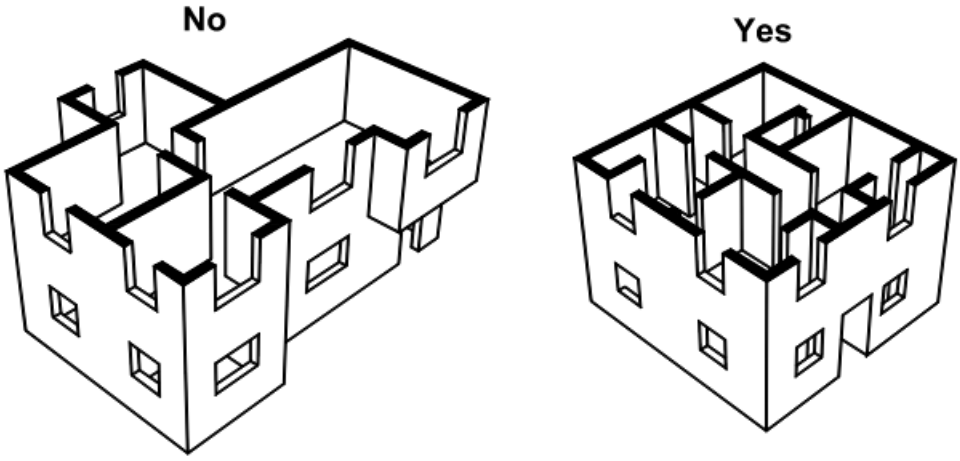


Figure 5: Wall layout (credit: Seismic Design Guide for Low-Rise Confined Masonry Buildings)

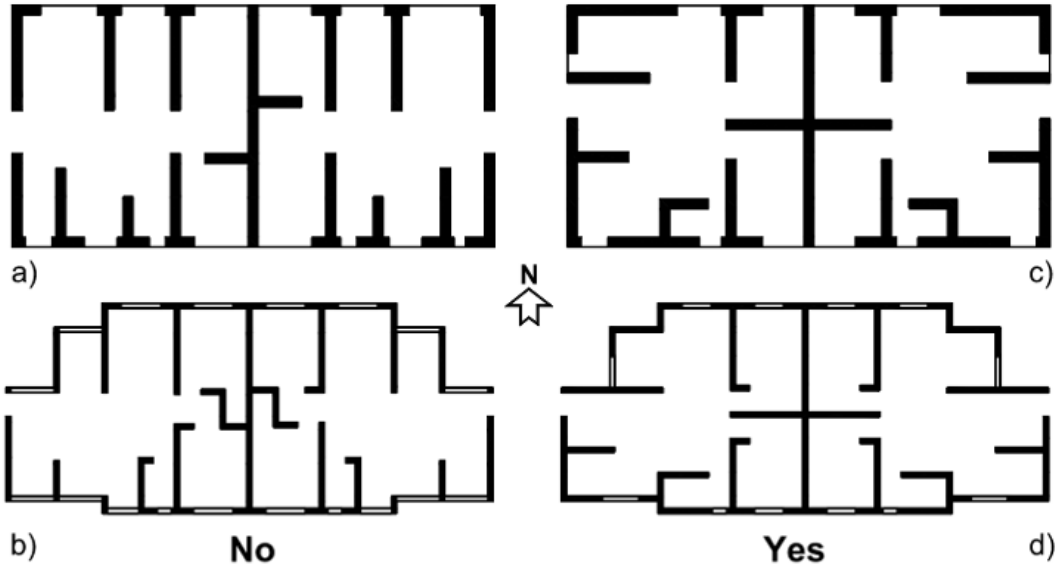


Figure 6: Wall distribution in plan: a) and b) not enough walls in the E-W direction; c) and d) possibly adequate wall lengths in both N-S and E-W directions (note a few strong walls on the perimeter of the plan). (credit: Seismic Design Guide for Low-Rise Confined Masonry Buildings)

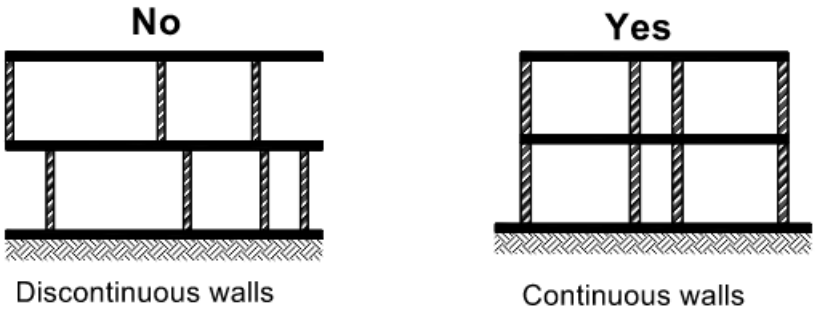


Figure 7: Continuity of walls between storeys (vertical sections shown). (credit: Seismic Design Guide for Low-Rise Confined Masonry Buildings)

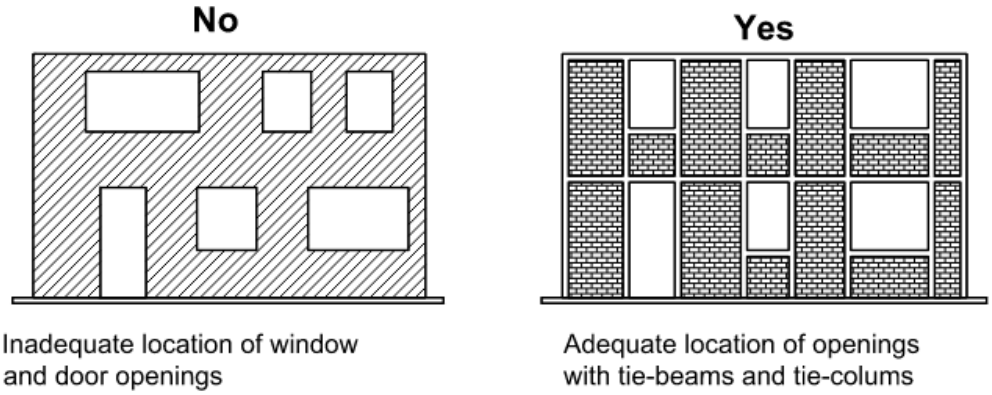


Figure 8: Location of openings in a building. (credit: Seismic Design Guide for Low-Rise Confined Masonry Buildings)

7. Soft Stories: Floors should be consistent in height and stiffness, and walls should carry to the floor to prevent soft stories. (Figure 9)

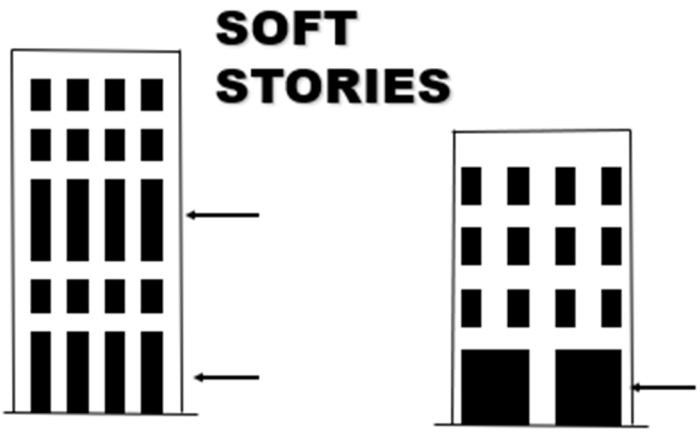


Figure 9: Soft Stories (credit: Derek Hanson)

8. Pounding: Building placed too close to each other can ram into each other. For buildings with one to five stories, the required pounding separation must maintain a minimum of 200 mm (8 in) or 2% of the building height whichever is greater.

3.2 ELEVATION & OPENINGS

The elevation of a CM building is formed from the concrete columns and masonry walls. The elevation always has concrete columns at building corners and at given intervals in between. Masonry is placed between the columns to form walls. In CM, small openings may be formed within the masonry alone or a simple concrete lintel and should be limited to 10% of the wall area.

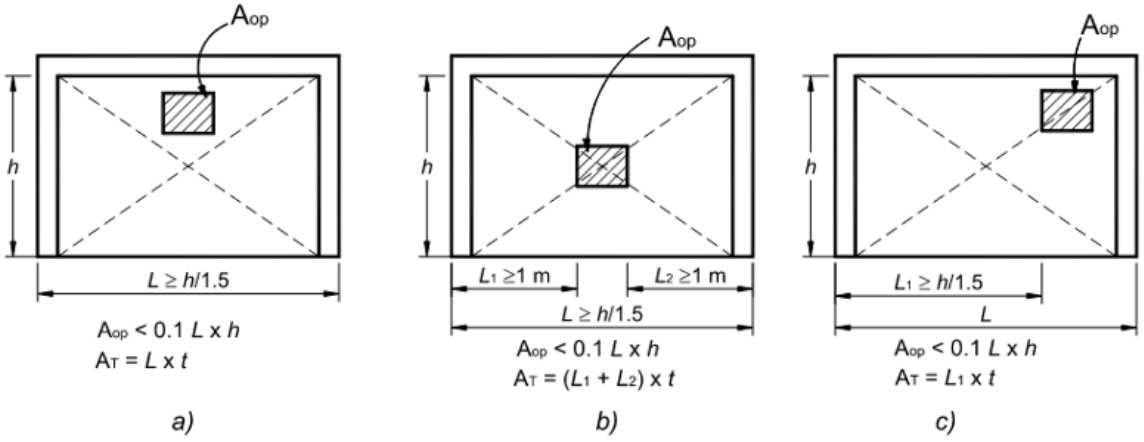


Figure 10: CM wall panel with a small opening: a) an opening outside the diagonals can be neglected; b) and c) opening must be taken into account. (credit: Seismic Design Guide for Low-Rise Confined Masonry Buildings)

In CM construction, openings greater than 10% of the wall area should be confined with reinforced concrete tie columns on each side, with a concrete header above and sill below. Smaller openings need only a lintel and sill. The remaining wall to either side of the opening may be used as shear wall in wall area calculations. (see Figure 11 and wall density method in Section 5.1)

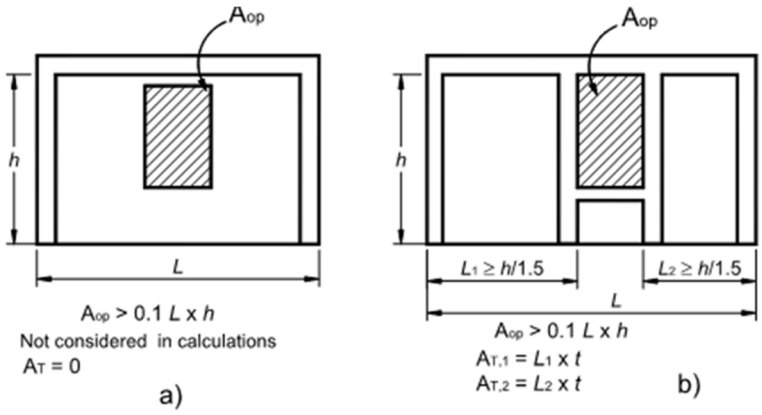


Figure 11: Masonry wall with a large opening: a) this is an unconfined panel - to be disregarded in wall density calculations; and b) RC tie-columns are provided at the opening, and two confined wall panels can be considered in the wall density calculations. (credit: Seismic Design Guide for Low-Rise Confined Masonry Buildings)

Where buildings have a triangular gable end wall that extends to the roof, the masonry in the gable should also be confined with a concrete ring beam. See section 6.5 for more details.

3.3 FOUNDATIONS & PLINTH BEAM

The foundation can be formed with compacted gravel/stone or with poured in place concrete. For both cases, a trough or trench is dug within the soil and filled with the foundation material. Most often, pad footings (under columns) and/or strip footings (continuous under walls) are utilized.

Once the foundation is laid, a plinth wall is then built to the slab level. This plinth is typically an unreinforced masonry wall until it reaches slab level. Often, a first concrete beam is cast directly on top of the plinth. This is a horizontal reinforced concrete beam that serves as a tension and compression tie between the base of the columns to be cast above. The plinth is formed up to the finished grade of the surrounding soil.

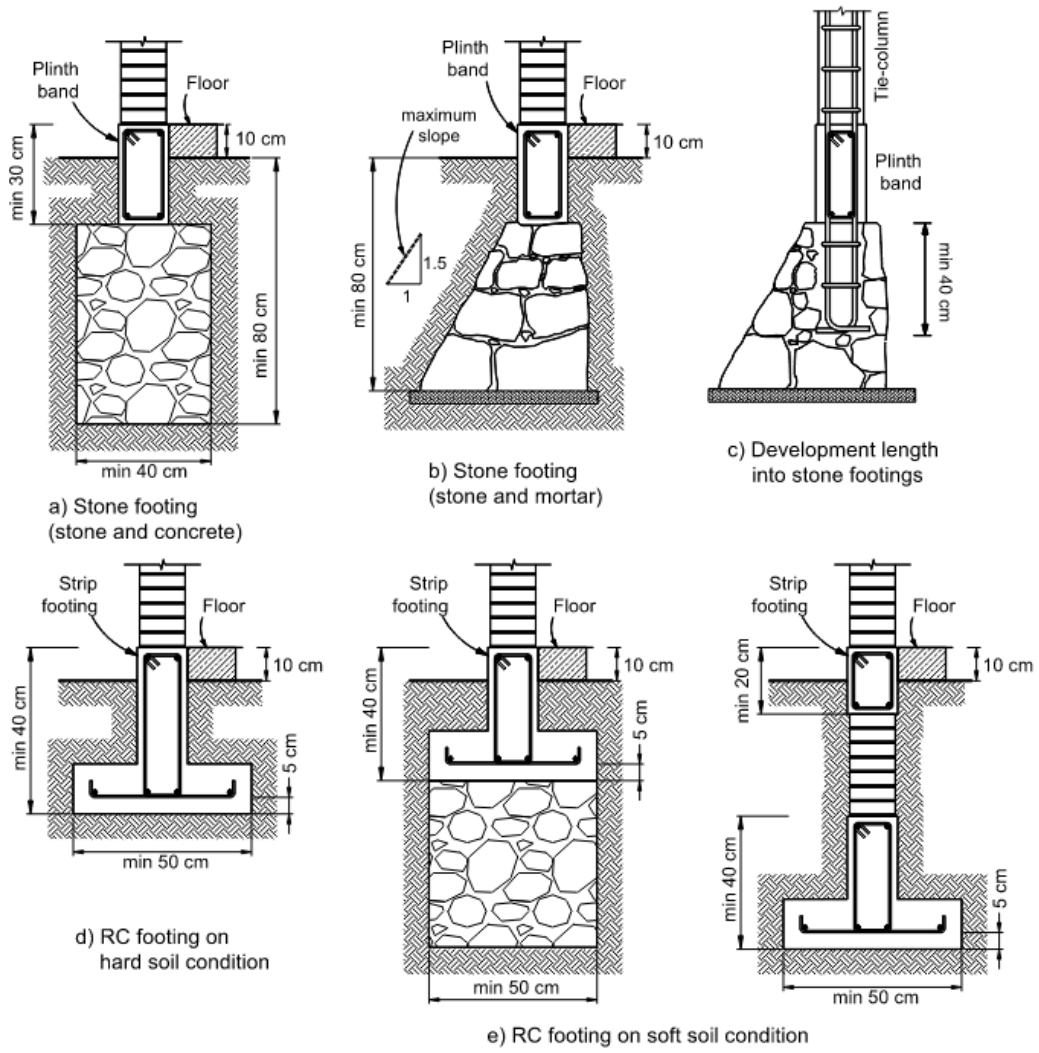


Figure 12: Foundation details for CM construction (credit: Seismic Design Guide for Low-Rise Confined Masonry Buildings)

4 Confined Masonry Elements

4.1 SYSTEM OVERVIEW

Confined masonry and infill frames use the same materials (concrete, reinforcing steel, and masonry units) to produce columns, beams, and walls. The two systems differ in construction sequence, reinforcing, and the interface between masonry and concrete, as described in Section 1.2 Construction and Section 4.5 Construction Sequence. This section describes the elements of CM; tie columns and ring beams are the same elements an infill frame calls columns and beams.

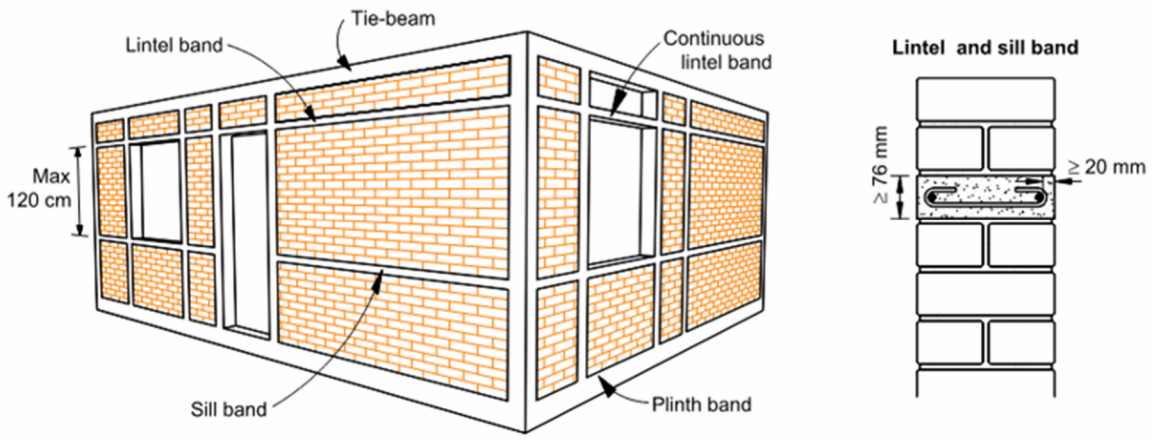


Figure 13: Intermediate RC ring beams can be provided to enhance the out-of-plane wall resistance (credit: Schacher, 2009)

4.2 TIE COLUMNS

Tie columns are constructed of vertical reinforced concrete elements. They are placed at building corners and intermediate vertical support locations. Confining columns can be added on either side of door and window openings. Often these columns are spaced between 3 and 5 m (10-15 ft) apart.

4.3 TIE BEAMS

Tie beams or ring beams are constructed of horizontal reinforced concrete elements, they are also sometimes referred to as tie beams. They are placed at building foundation, floor, and roof levels at horizontal support locations. Confining ring beams can be added on the top and bottom of door and window openings. Often levels are around 3 m (10 ft) of elevation. Ring beams are often 200 to 300 mm (8”-12”) deep. These are different than lintel and sill bands, which do not carry on past confining columns and only exist to support openings.

4.4 MASONRY WALL PANELS

The masonry wall panels can be constructed of any brick or block like elements stacked together to form a wall. These blocks can be formed of concrete, clay, or stone and can be hollow or solid in structure. The blocks are typically placed together with a mortar material to provide a bond between the surfaces and a chance for levelling nonuniform brick sizes. Bricks can be laid in different orientations—header or stretcher courses—for various wall thicknesses from 100-300 mm (4”-12”). Thicker walls often perform better.

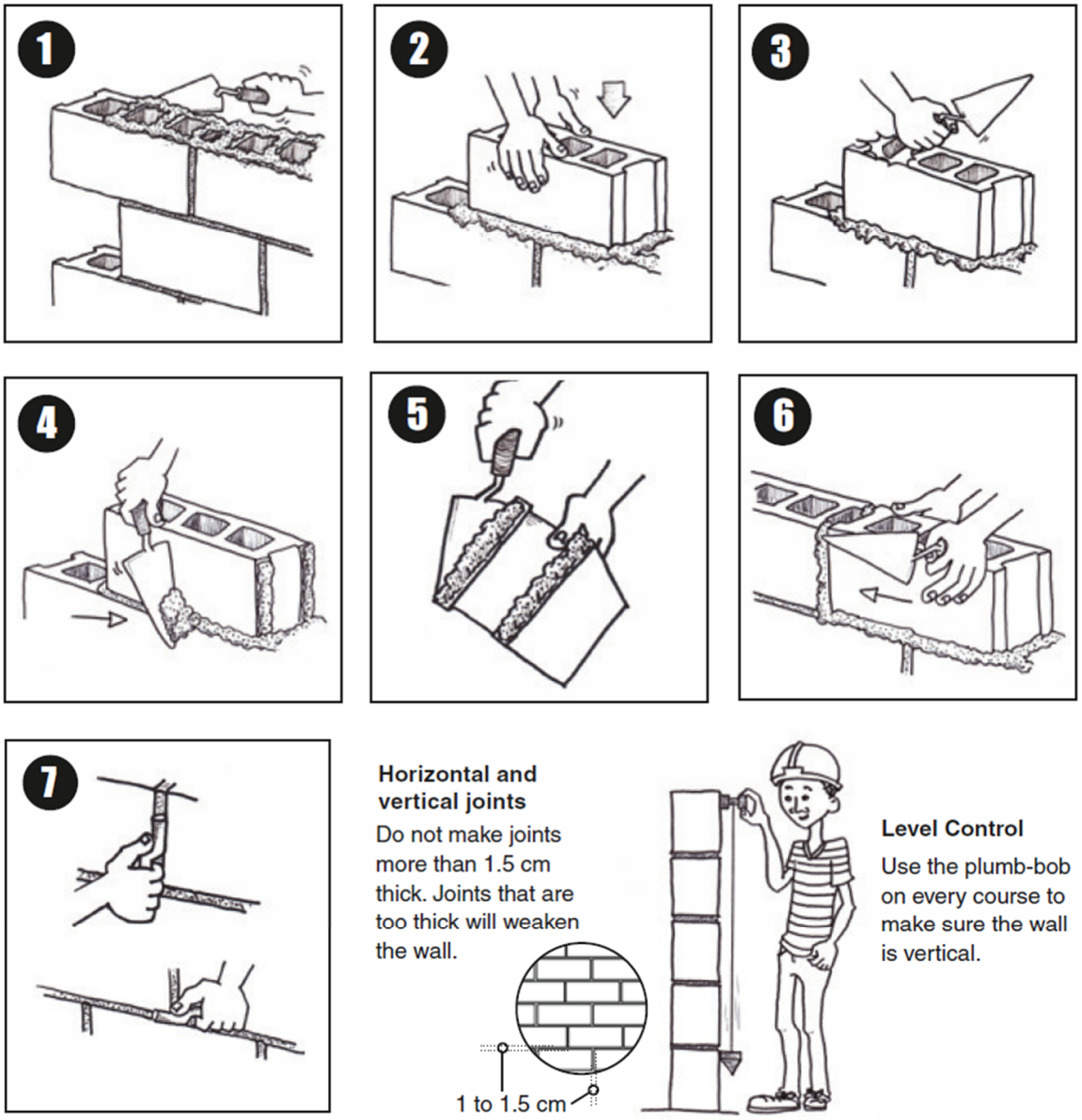


Figure 14: Laying the blocks (credit: Totten, Confined Masonry Workshop Manual, 2010)

4.5 CONSTRUCTION SEQUENCE

The sequence of construction is a key distinguishing feature of CM from an infill frame.

In an infill frame, the interaction between the brick and the concrete is a well-defined continuous mortar joint. When the building begins to rack back and forth this joint can be dislodged and the wall panel can fall out of plane either into the building or out of the building. These walls then become a dangerous falling hazard to both the building inhabitants and those walking outside. Loss of the wall also translates to a loss of lateral stability if the concrete is not designed as a moment frame system independent of the wall.

In an infill frame, the concrete is formed first, and the brick wall material is stacked inside the concrete frame. Metal strapping can be added to improve the connection from the column to the masonry, but the building remains an infill frame, not CM.

In CM construction, the wall is built first, and the concrete tie columns and ring beams are cast against it. The masonry at each column is toothed (staggered) to produce a key joint that locks the wall into the column.

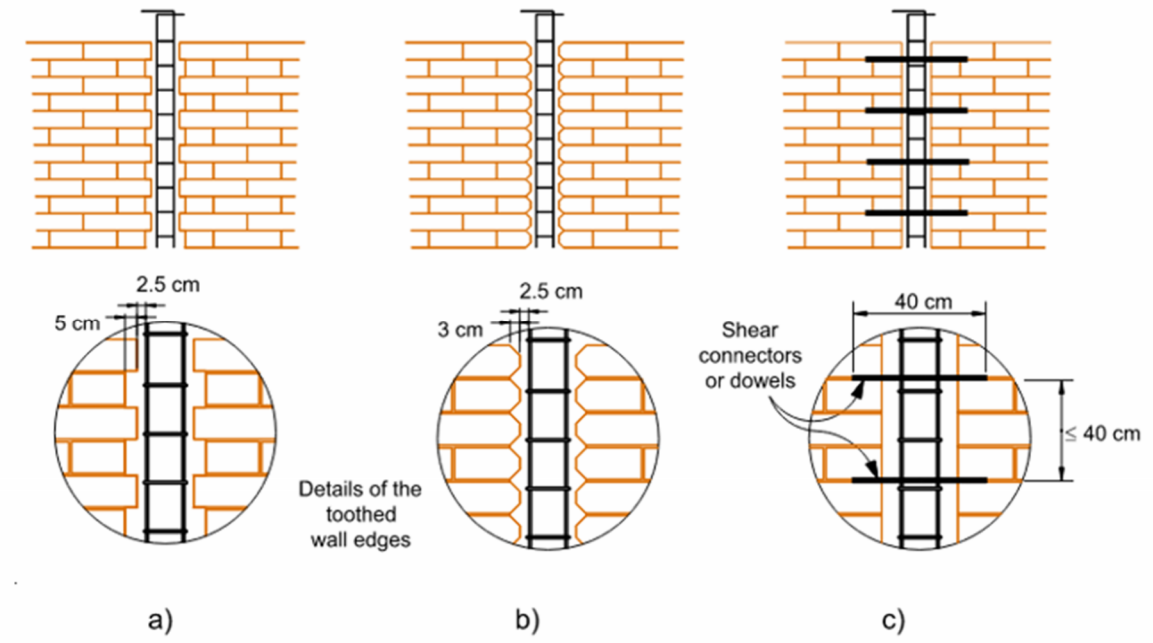


Figure 15: Toothing in CM walls: a) machine-made hollow units, b) hand-made solid units, and c) provision of horizontal reinforcement when the toothing is not possible (credit: Seismic Design Guide for Low-Rise Confined Masonry Buildings)

The keyed condition of the brick provides a stronger interlocked connection between the brick and concrete materials. When a building of this construction begins to rack back and forth the joint remains stronger and better contains the brick wall within the building. Lateral loads can then be transferred through this interlocked joint.

5 CM Analysis Methods

5.1 WALL DENSITY INDEX METHOD

A simple method for assessing the seismic behaviour of CM buildings less than 3 storeys tall is the Wall Density Method (WDM). To apply the WDM, the total usable wall area (Aw) is added up in each principal direction for the ground floor. Usable wall area includes all walls without penetrations that are enclosed by concrete beams or columns. Divide this number by the total area of the floor/roof above (Ap). The resulting number is compared to the Wall Density Index (WDI) from the table below to determine the adequacy of the amount of wall resisting lateral forces in that direction. Perform in each principal building direction. Confined masonry walls and masonry infill walls are treated the same in the WDM: an infill wall that meets the same criteria (no penetrations, enclosed by concrete beams and columns) is counted in Aw in the same way as a CM wall. Eurocode 8 (EN 1998-1, Section 9.7) uses a similar check for “simple masonry buildings,” setting a minimum wall area in each direction as a percentage of floor area.

d = Aw/Ap > WDI (from Table 1)

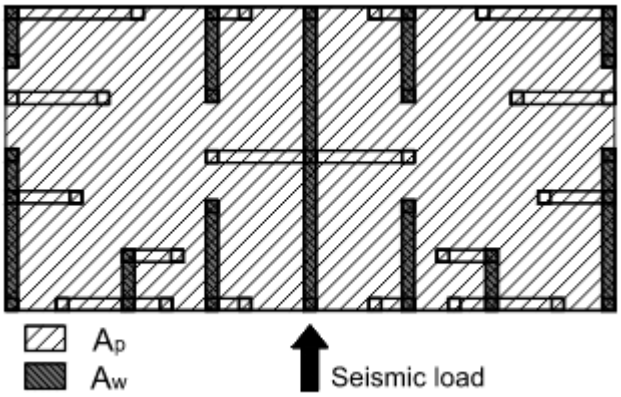


Figure 16: Wall Density Index Parameters (credit: Seismic Design Guide for Low-Rise Confined Masonry Buildings)

Table 1: Wall Density Index *d*(%) for each direction of the building plan (credit: Seismic Design Guide for Low-Rise Confined Masonry Buildings)

Number of Stories (*n*)	Seismic Hazard				
	Low	Moderate		High	
	Soil Type A, B, or C	Soil Type A	Soil Type B or C	Soil Type A	Soil Type B or C
Solid clay bricks (mortar type I, II, and III) Solid concrete blocks (mortar type I)					
1	1.0	1.0	1.0	1.5	2.5
2	1.5	1.5	2.0	3.0	4.5
Solid concrete blocks (mortar type II and III) Hollow concrete blocks (mortar type I) Hollow clay bricks (mortar type I)					
1	1.0	1.0	2.0	2.0	3.5
2	1.5	1.5	3.5	4.0	6.5
Hollow concrete blocks or hollow clay bricks (mortar type II and III)					
1	1.0	1.5	2.5	3.0	5.0
2	2.0	3.0	5.0	6.0	9.5

Note:

Soil Types: A: Rock or Firm Soil, B: Compact granular soil, C: Soft clay soil or soft sand

Method assumes: uniform building plans (regular footprint), nearly symmetric wall layout, floor acts as rigid diaphragm

5.2 PERUVIAN NTE E.070 STANDARD

Where existing one- to five-story-tall CM buildings have been constructed, an alternative calculated method may be considered using the equation below to compare to the wall density percentage d, calculated the same way as above, in Section 5.1.

> "If we simplify the material performance factor to standard bricks, it mirrors the Peruvian NTE E.070 standard:
>
> $$d = Aw/Ap \geq \frac{Z * U * S * N}{56}$$
>
> Where:
>
> - *Z* = Seismic Zone factor (ranging from 0.1 for low to 0.45 for very high hazard)
> - *U* = Importance factor (1.0 for standard housing)
> - *S* = Soil profile factor (1.0 for rock, scaling up to 1.2 or 1.4 for soft soil)
> - *N* = Number of stories

- *d = wall density %*

Because *N* acts as a linear multiplier in the numerator, the required wall density strictly multiplies with each floor added. That is why a 1-story building requiring roughly 1.5% density automatically scales up to 4.5% at 3 stories, and 6.0% to 7.5% at 4 or 5 stories for most seismic loads."

Z is approximately the 475-year peak ground acceleration on rock, in g. Outside Peru, read the PGA from the hazard map in Section 5.3.1 and use the next-higher E.030 zone value (0.10, 0.25, 0.35 or 0.45). Where PGA exceeds 0.45g, use the Base Shear Method (Section 5.3).

(Peru's NTE E.070 — Norma Técnica de Edificación E.070 "Albañilería", Article 19)

5.3 BASE SHEAR METHOD

5.3.1 SEISMIC LOADS

The following procedure may be used to determine the design seismic loads on a CM building.

Determine the 475-year PGA (peak ground acceleration)

Using the GSHAP world seismicity map (Figure 17), find the 475-year peak ground acceleration (PGA) at the site. Convert to g's by dividing by 9.81 if given in m/s^2 (or by 32.2 if given in ft/s^2). The result is the 475-year PGA in g's.

Estimate Ss, then convert to Sds

Estimate the short-period spectral acceleration as Ss ≈ 2.5 × PGA (a standard approximation for the plateau of a typical response spectrum when only a PGA map is available). Apply the site coefficient: SMS = Fa × Ss (Fa = 1.0 for rock or firm soil). Then convert from the maximum-considered-earthquake level to the design level: Sds = (2/3) × SMS. As a combined estimate, for firm soil this works out to roughly Sds ≈ 1.67 × PGA.

Find the Base Shear Coefficient

Using the formula Cs = Sds / R (assuming a standard-occupancy importance factor, Ie = 1.0; essential facilities such as schools or clinics require a higher Ie (between 1.25 and 1.5) and should not use this simplified form, detailed analysis by a professional

engineer should be sought), calculate Cs. R for confined masonry may be taken as follows:

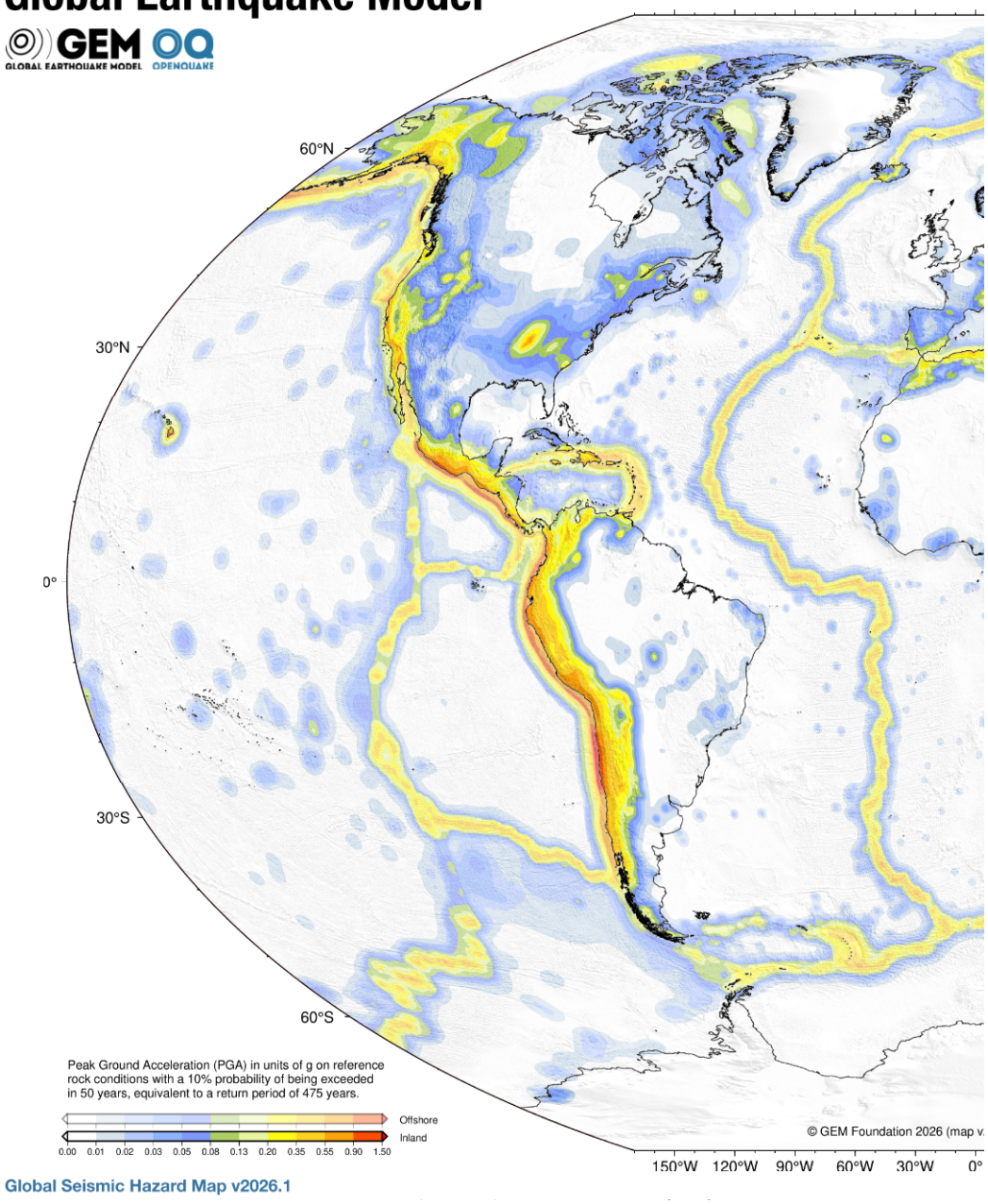
R = 2 for poorly detailed confined masonry

R = 3 for well-detailed CM

These R values fall within the behaviour factor range of q = 2.0 to 3.0 that Eurocode 8 (EN 1998-1, Table 9.1) gives for confined masonry.

Find the Base Shear

For short buildings (three stories or less), the seismic base shear is Cs × W, where W is the weight of the building (see Section 7.1, which gives typical CM building weights around 9.6 kPa/200 psf per floor).



Global Seismic Hazard Map v2026.1

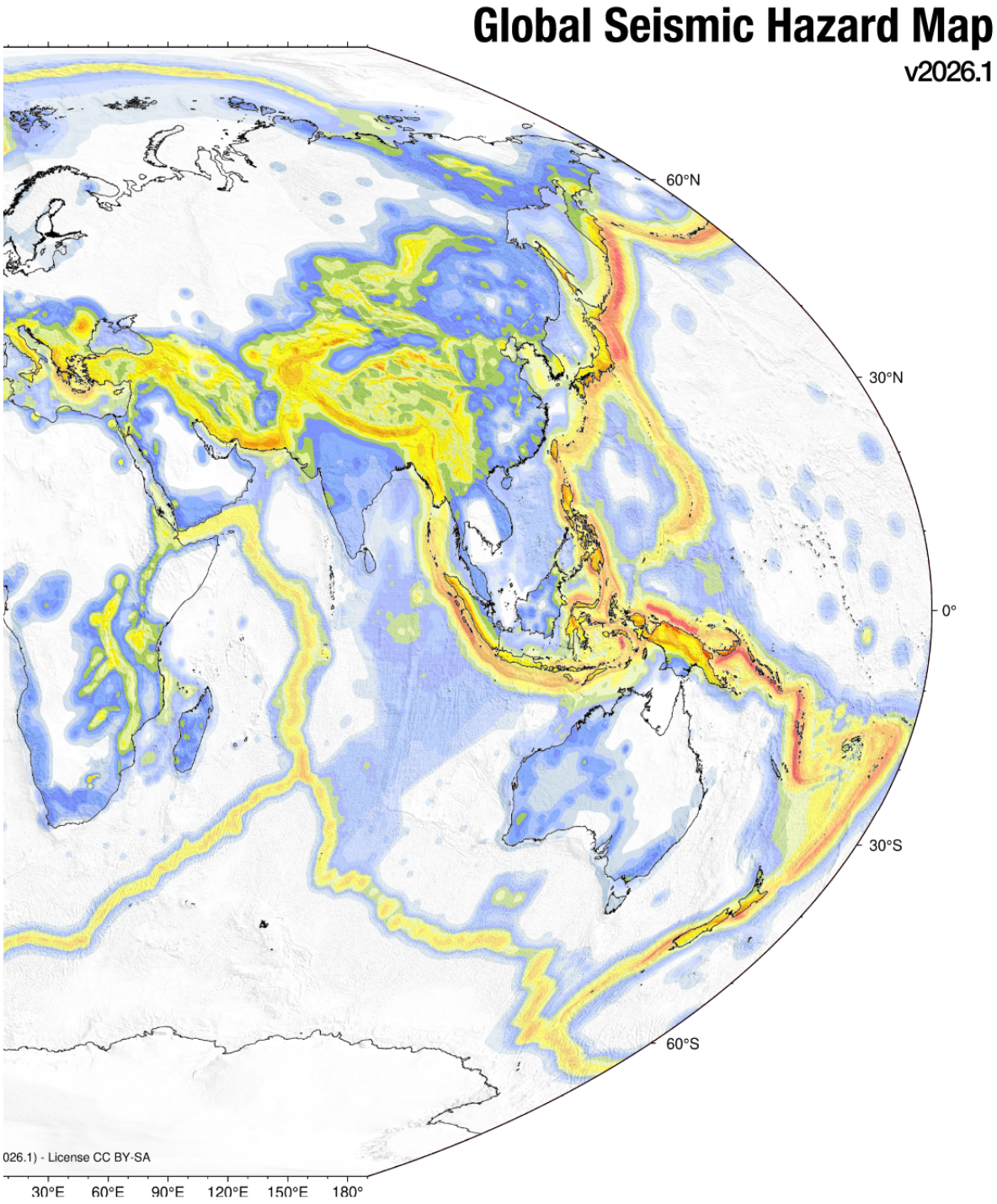


Figure 17: Global Seismic Hazard Map (credit: Global Earthquake Model Foundation)

5.3.2 WALL SHEAR CAPACITY

Masonry Wall Shear Strength (VR), for comparison against base shear (VU)

Determine the total effective wall area (Aw) in the direction being checked. Sum the cross-sectional area (length × thickness) of every wall running in that direction at the story level you're evaluating. Leave out any wall where the height-to-length ratio exceeds 1.5 (H/L > 1.5), and any wall where unconfined openings take up more than 10% of the wall's surface area — neither counts toward Aw.

Find the basic masonry shear strength (vm). Use diagonal compression test data for your local materials if you have it; otherwise use the vm values below in Table 3 (by masonry unit and mortar type). Eurocode 6 (EN 1996-1-1) gives an equivalent approach, in which masonry shear strength is an initial shear strength that increases with the compressive stress on the wall.

Table 2: Mortar Mix Proportions and Compressive Strength (f'_j)

Type of mortar	Hydraulic cement	Masonry cement	Hydrated lime	Sand	Nominal compressive strength, f'_j MPa (psi)
I	1	–	0 to ¼	Not less than 2.25 nor more than 3 times the total cementitious materials, by volume	12.5 (1,800)
	1	0 to ½	–		
II	1	–	¼ to ½		7.5 (1,100)
	1	½ to 1	–		
III	1	–	½ to 1		4.0 (580)

(credit: Seismic Design Guide for Low-Rise Confined Masonry Buildings, Table 3; source values from NTC-M, 2004)

Table 3: Basic Shear Strength of Masonry (vm)

Type of masonry unit	Type of mortar	Basic shear strength, v_m MPa (psi)
Solid clay bricks	I	0.35 (51)
	II and III	0.30 (44)
Hollow clay units	I	0.30 (44)
	II and III	0.20 (29)
Hollow concrete blocks	I	0.35 (51)
	II and III	0.25 (36)
Solid concrete blocks	I	0.30 (44)
	II and III	0.20 (29)

(credit: Seismic Design Guide for Low-Rise Confined Masonry Buildings, Table 5; source values from NTC-M, 2004)

Compute the average compressive stress (σ) from gravity loads. σ = total building weight tributary to that story ÷ total wall cross-sectional area in both orthogonal directions combined at that level (gravity load is carried by all walls, not just the ones in the direction you're checking). Use σ = 0 if the walls are ever in net tension rather than compression.

Compute the masonry shear strength (v). v = 0.5·vm + 0.3·σ, but capped at v ≤ 1.5·vm — use whichever of the two is smaller.

Compute the wall shear strength (VR). VR = v × Aw, using the direction-specific Aw from Step 1.

Compare to base shear demand. Check VR ≥ VU, where VU is the seismic base shear from the earlier procedure (Cs × W). If VR is less than VU in either direction, the wall area in that direction is inadequate for the demand as calculated.

6 Diaphragms & Connections

6.1 CONCRETE DIAPHRAGMS

Concrete diaphragms in CM buildings (horizontal floors or roofs) rarely need a lot of engineering. Due to the close spacing of CM walls in plan, diaphragm stresses are low and the reinforced concrete slabs, typically 100 mm (4") thick, can easily accommodate them.

6.2 LIGHT GAUGE CORRUGATED STEEL ROOF

Typical light roofs consist of:

- wood trusses supporting purlins supporting corrugated metal deck or
- steel or rebar trusses supporting purlins supporting corrugated deck.

Figure 18 shows these typical details.

6.3 WALL ANCHORAGE TO DIAPHRAGM

Unless there are many cross-walls, anchorage of CM walls to the roof diaphragm is a critical load path in seismic resistance. Once the roof separates from the wall, the wall is very susceptible to collapse.

A very simplified calculation for force to be transmitted through this connection is:

$$Fp = 0.4 \times Wp$$

Where Fp is force per unit length, and Wp is the tributary weight of wall (usually ½ the wall height x the wall weight).

0.4 is quite conservative, check the codes for lower risk areas and uses. A more sophisticated formula is found in the IBC 1604.8.2, ASCE 7, Section 12.11.2.1. The 0.4 × Wp shorthand is the ASCE 7 formula Fp = 0.4 × Sds × ka × Ie × Wp with Sds × ka × Ie taken as 1.0; where the site's Sds (Section 5.3.1) is higher, use the full formula. Roof anchorage must also resist wind uplift, which often governs light roofs. Roof sheets, purlins and their fasteners are designed for the higher component-and-cladding wind pressures (see EMI Structural Design Guide, Section 7.1).

Wall anchorage capacity must be calculated for the particular condition. If wood framing is anchored to the concrete ring beam, anchor pull out from the concrete, anchor yield, and anchor to wood failure must all be checked for the lowest capacity.

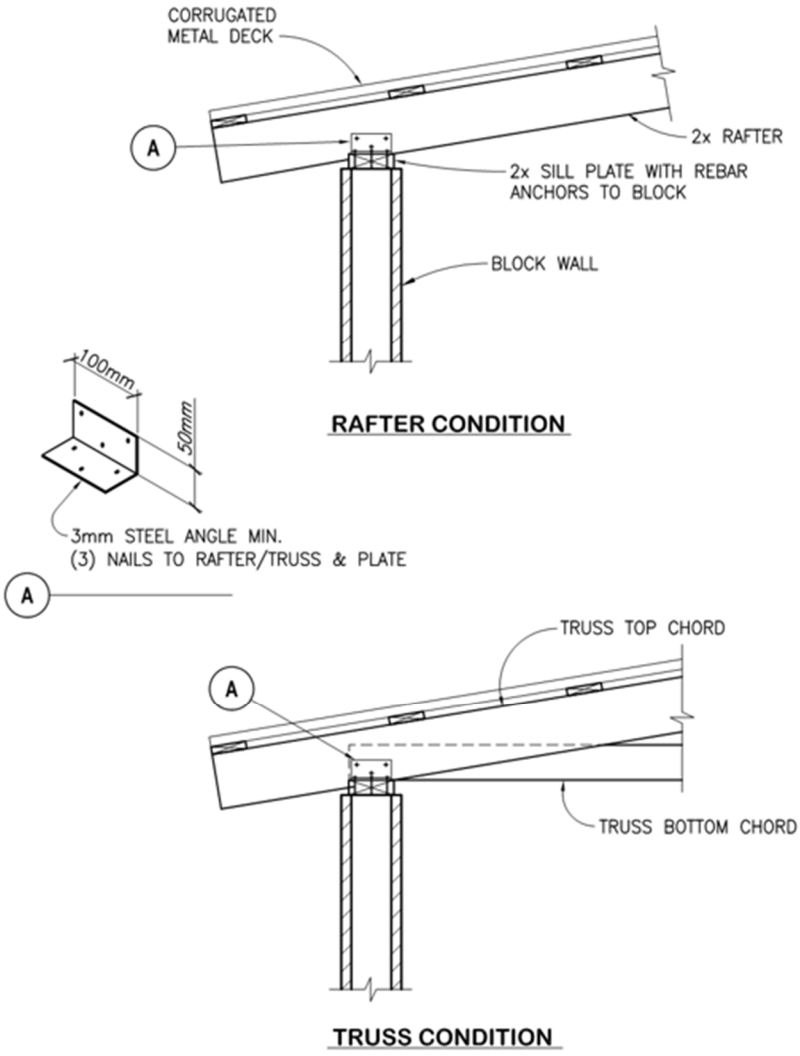


Figure 18: Typical Roof to Wall Anchorage Connection (credit: Eric Lehmkuhl)

6.4 DIAPHRAGM DESIGN

Typical corrugated deck has limited diaphragm capacity. Diaphragms are typically modelled as simply supported beams spanning between walls to support the lateral loads imposed at the top of a wall. Therefore, the distance between CM walls cannot be too long for a given depth of diaphragm.

Table 4, below, gives some approximate maximum diaphragm spans for a one-story CM building with a 22 mm (7/8″) corrugated deck.

Table 4: Span versus Depth for Corrugated Roofs

Diaphragm Depth (D)		Diaphragm Span (B), between walls	
meters	feet	meters	feet
3.05	10	8.23	27
6.1	20	13.72	45
9.1	30	20.73	68

Diaphragm capacity = 2.92 kN/m^2 (200 plf)

2.39 kPa (50 psf) wall; 0.48 kPa (10 psf) roof

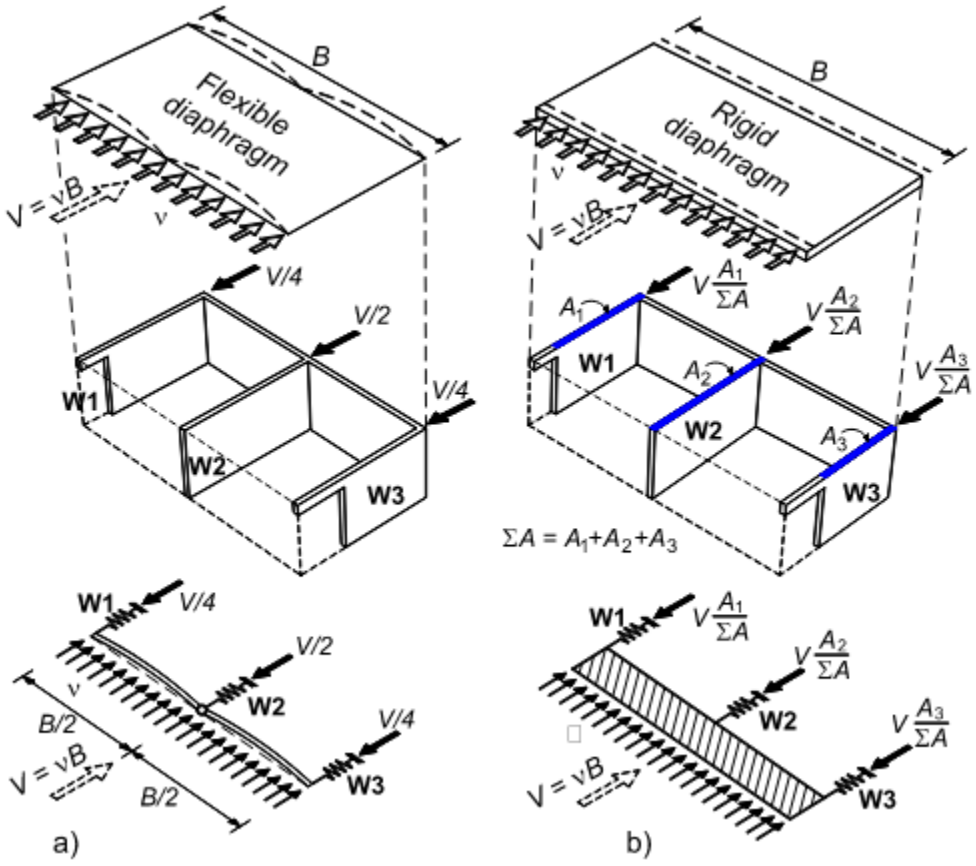


Figure 19: Flexible vs Rigid diaphragms.
In Table 4 above, depth (D) is the distance of the diaphragm along the wall and span (B) is the distance between walls. (credit: Seismic Design Guide for Low-Rise Confined Masonry Buildings)

Fastening and overlap and connection from roof to walls are critical to get diaphragm support. Bracing should be added if stresses in diaphragm are too high. Sheet-metal diaphragm capacity is governed by its connections, so specify and check fastener type and spacing (see EMI Structural Design Guide, Section 8.6).

Ring beam design can also support roofs through the out of plane direction.

6.5 GABLE END WALLS

Large gable walls are often found in churches and other assembly buildings. Even if the top of the wall is anchored, there can be an out-of-plane “blow out” between the roof and ceiling (See Figure 20). This can be mitigated by adding a ring beam at the top of the wall (bottom of roof), adequate wall to roof anchorage, and continuing concrete columns to the roof.

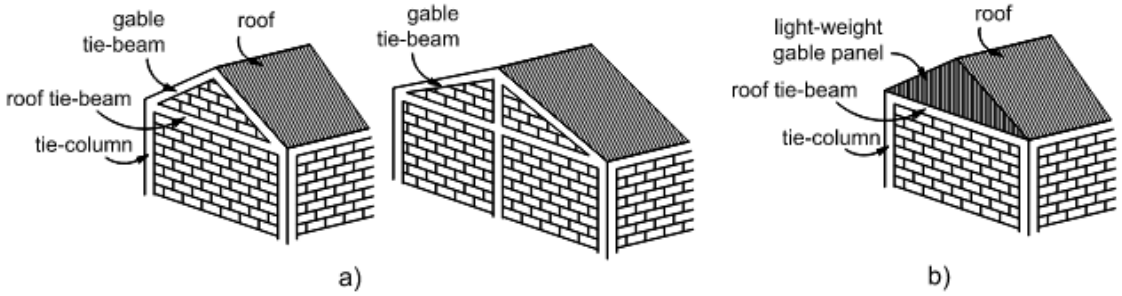


Figure 20: Gable end roof walls (credit: Seismic Design Guide for Low-Rise Confined Masonry Buildings)

7 Hazards

The major environmental hazards affecting confined masonry buildings are seismic events, high winds, and flooding. This document will address seismic and wind only.

7.1 SEISMIC

7.1.1 VULNERABILITY

CM buildings tend to be heavy compared to steel or wood buildings. This is particularly true when they are more than one story or have a concrete slab roof. The combination of concrete floors and masonry walls makes for a heavy building that generates large seismic forces. For example, a typical CM building might weigh around 9.6 kPa (200 psf) per floor, while a wood-framed building is around 2.4 kPa (50 psf) per floor.

CM walls have very limited ductility. They are quite brittle and do not have a yield plateau. Therefore, they must be designed as near-elastic.

CM walls have a very limited displacement capability. After approximately 0.5% drift they will typically lose strength rapidly. This and the limited ductility mean that CM buildings must have a lot of walls. See Figure 21 for test data showing a stiff wall with a rapidly dropping strength at around a drift of 0.005 (13 mm over a 3 m [1/2" over 10 ft] story).

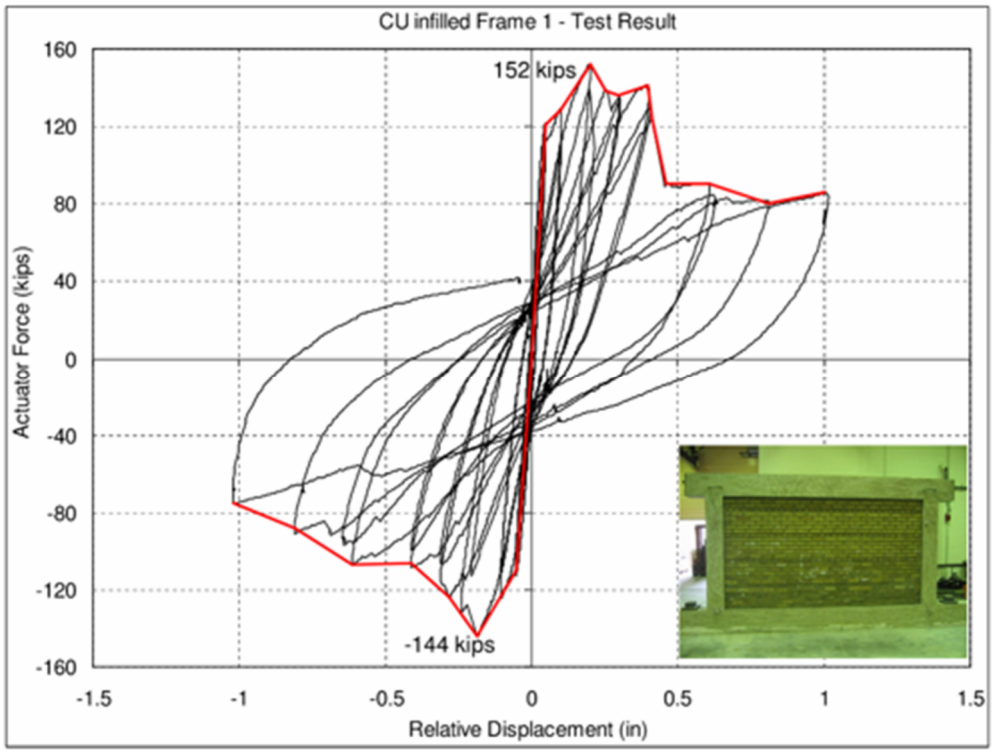


Figure 21: Graph showing a stiff wall with a rapidly dropping strength (credit: University of Colorado)

7.2 WIND

7.2.1 VULNERABILITY

Due to the prevalence of CM construction worldwide, these buildings often occur in high wind zones. CM walls themselves are quite resistant to in-plane shears from high winds. The vulnerability of this construction is mainly due to the use of light framed roofs, especially for single story buildings. These light roofs are often poorly anchored to the walls and provide very little diaphragm strength.

7.2.2 WIND LOADS

Search the available literature for local design wind speeds or wind loads. Keep in mind that ASCE 7 wind loading is a strength level wind based on a 700-year mean recurrence interval (for standard buildings, more for essential structures).

Typical service-level design wind speeds (3-second gust, about a 50-year return period) are 27 to 46 m/s (60 to 100 mph), with the higher values associated with hurricane winds. Ultimate-level speeds used with ASCE 7 are higher. Before using any wind speed, confirm its basis (return period and averaging time) and convert it to match the design method (see EMI Structural Design Guide, Section 5.4).

Final design pressures for a one- to three-story building should be in the range of 1.0 to 2.4 kPa (20 to 50 psf).

Refer to local codes for design speeds.

8 Inspection, Assessment, & Retrofit

This section applies the concepts presented in earlier chapters to field inspection, damage assessment, posting decisions, and retrofit considerations for confined masonry buildings.

The goal of a post-event assessment is life safety. The aim is to keep people safe, not to prevent or repair every instance of minor damage. Bring your engineering expertise, but leave your home-country practice behind: recommendations should make the building better without drastically increasing cost, using locally available materials and methods. Masonry walls, whether confined or infilled, are a brittle and heavy lateral system, so look for the conditions that lead to sudden loss of strength rather than gradual yielding.

8.1 POST EVENT INSPECTION CHECKLIST

Inspections of damaged structures begin with a thorough visual assessment from the outside before proceeding inside if it is safe to do so. See the Evaluation Checklist in Post-event Assessment (Section 8.4) for the full safety procedure. Early in the inspection, identify whether the building is CM or an infill frame. Toothed masonry at the column edges (visible where plaster is damaged or absent) indicates CM; a straight vertical joint between masonry and column indicates an infill frame, whose walls are more likely to fall out of plane.

See Appendices for ATC 20 printable checklists.

8.2 COMMON PROBLEMS

Cracks are a map of loads. Their location, direction, and width show how forces travelled through the building and which elements are carrying, or have lost, load. Read the crack pattern first, then use it to decide where to look next.

In seismic events, CM construction is often widely impacted. Damage is generally worse at the lower levels and minimizes towards the top of the building. Common problems include:

1. X-cracks form in the brick infill walls due to diagonal shear failure. (Figure 22)
2. Shear or flexural cracking in concrete columns. (Figure 23)
3. Infill walls dislodged out of plane (Figure 24)
4. Pounding between two buildings
5. Soft story damage or collapse (Figure 25)



Figure 22: Diagonal Shear Failure in CM Wall (credit: Derek Hanson)



Figure 23: Column Shear Failure (credit: Derek Hanson)



Figure 24: Infill Wall Dislodged out of plane (credit: Craig Linquist)



Figure 25: Soft Story Collapse (credit: Derek Hanson)

In wind and flood events, CM construction generally performs well. Common problems are typically limited to light-framed roof diaphragms and window or door openings. Refer to Section 3 for more information about Pounding and Soft Stories

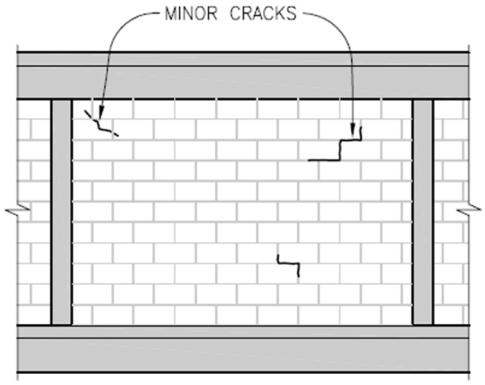
8.3 POST-EVENT ASSESSMENT

A final building assessment is essential to guide occupants or owners during recovery. It should include the time, date, location of the evaluation, and the organization or team conducting it. Use plan views or elevation sketches to clearly illustrate repair recommendations and include photos—at least one photo must show the entire front exterior of the building. Clearly identify safe and unsafe areas, explain the reasons for any unsafe conditions, and outline recommended next steps for repairs or further evaluation. A sample assessment form is included in the Appendices.

Once common damage patterns have been identified, the next step is to evaluate their severity and determine the appropriate occupancy status. Damaged CM walls can be categorized into one of five conditions:

1. Minor cracks in block or mortar with confining concrete relatively uncracked.
2. Small 1.6 mm (1/16”) diagonal or flat cracks in block or mortar with some crushing of block at corners and concrete relatively uncracked.
3. Large 3.2 mm (1/8”) diagonal or flat cracks in block or mortar with crushing of block at corners. Block may be falling out of joints and small cracks appear in concrete columns.
4. Larger than 3.2 mm (1/8”) + diagonal or flat cracks in block or mortar with crushing of block at corners. Block may be falling out of joints and large diagonal cracks appear in concrete columns.
5. Block has fallen out and concrete columns are cracked and spalled.

Having assessed the extent of the damage observed in a building, the diagrams in Figure 26 below can help determine the occupancy and options for repair.

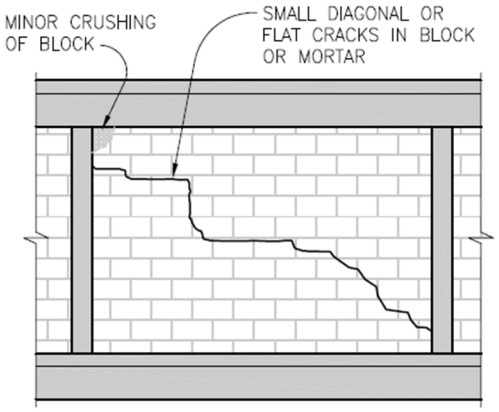


1

CONDITION:
BLOCK: MINOR CRACKS IN BLOCK OR MORTAR.
CONCRETE: RELATIVELY UNCRACKED.

OCCUPANCY:
SAFE TO OCCUPY.
STRENGTH 100% OF PRE–EARTHQUAKE STRENGTH.

REPAIR:
REPAIR BENEFICIAL BUT NOT CRITICAL.

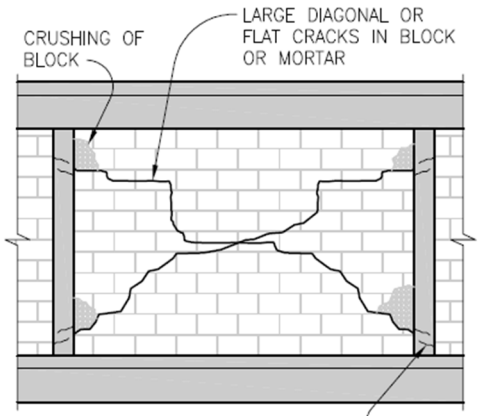


2

CONDITION:
BLOCK: SMALL ($\frac{1}{16}$") DIAGONAL OR FLAT CRACKS IN BLOCK OR MORTAR, SOME CRUSING OF BLOCK AT CORNER POSSIBLE.
CONCRETE: RELATIVELY UNCRACKED.

OCCUPANCY:
BUILDING MAY BE ENTERED TO RETRIEVE BELONGINGS. MAY BE SAFE FOR OCCUPANCY.
STRENGTH = 90% OF PRE–EARTHQUAKE STRENGTH

REPAIR:
MINOR PATCHING MAY BE SUFFICIENT.



3

CONDITION:

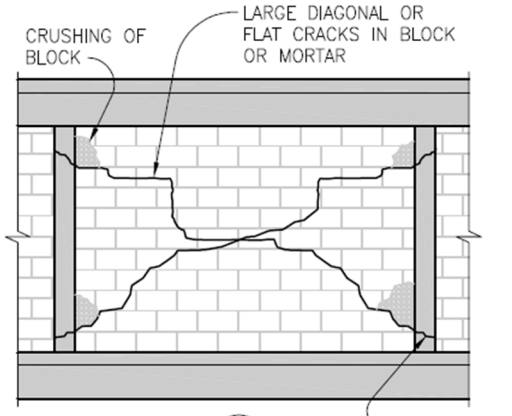
BLOCK: LARGE (⅛") DIAGONAL OR FLAT CRACKS. CRUSHING OF BLOCK AT CORNERS. MORTAR MAY BE FALLING OUT OF JOINTS.
CONCRETE: SMALL CRACKS APPEAR IN CONCRETE COLUMNS.

OCCUPANCY:

BUILDING MAY BE ENTERED TO RETRIEVE BELONGINGS. MAY BE SAFE FOR OCCUPANCY.
STRENGTH = 80% OF PRE-EARTHQUAKE STRENGTH

REPAIR:

OPTION 1: APPLY WIRE MESH REPAIR TO WALL
OPTION 2: REPLACE BLOCK ENTIRELY



4

CONDITION:

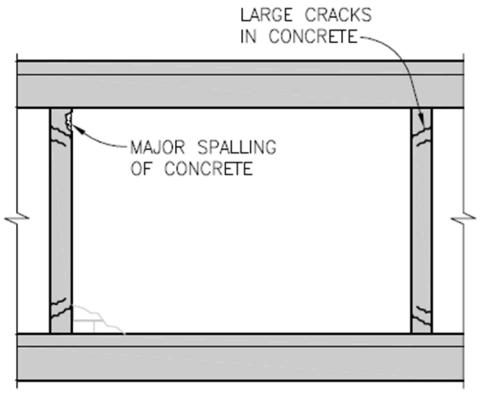
BLOCK: LARGE (⅛"+) DIAGONAL OR FLAT CRACKS. CRUSHING OF BLOCK AT CORNERS. LOSS OF MORTAR.
CONCRETE: LARGE DIAGONAL CRACKS IN COLUMN.

OCCUPANCY:

BLOCK ON THE VERGE OF COLLAPSE.
DO NOT ENTER OR OCCUPY
STRENGTH = 40% OF PRE-EARTHQUAKE STRENGTH

REPAIR:

REPLACE BLOCK ENTIRELY.
REMOVE BROKEN CONCRETE, ADD COLUMN TIES, RE-POUR COLUMNS.



5

CONDITION:

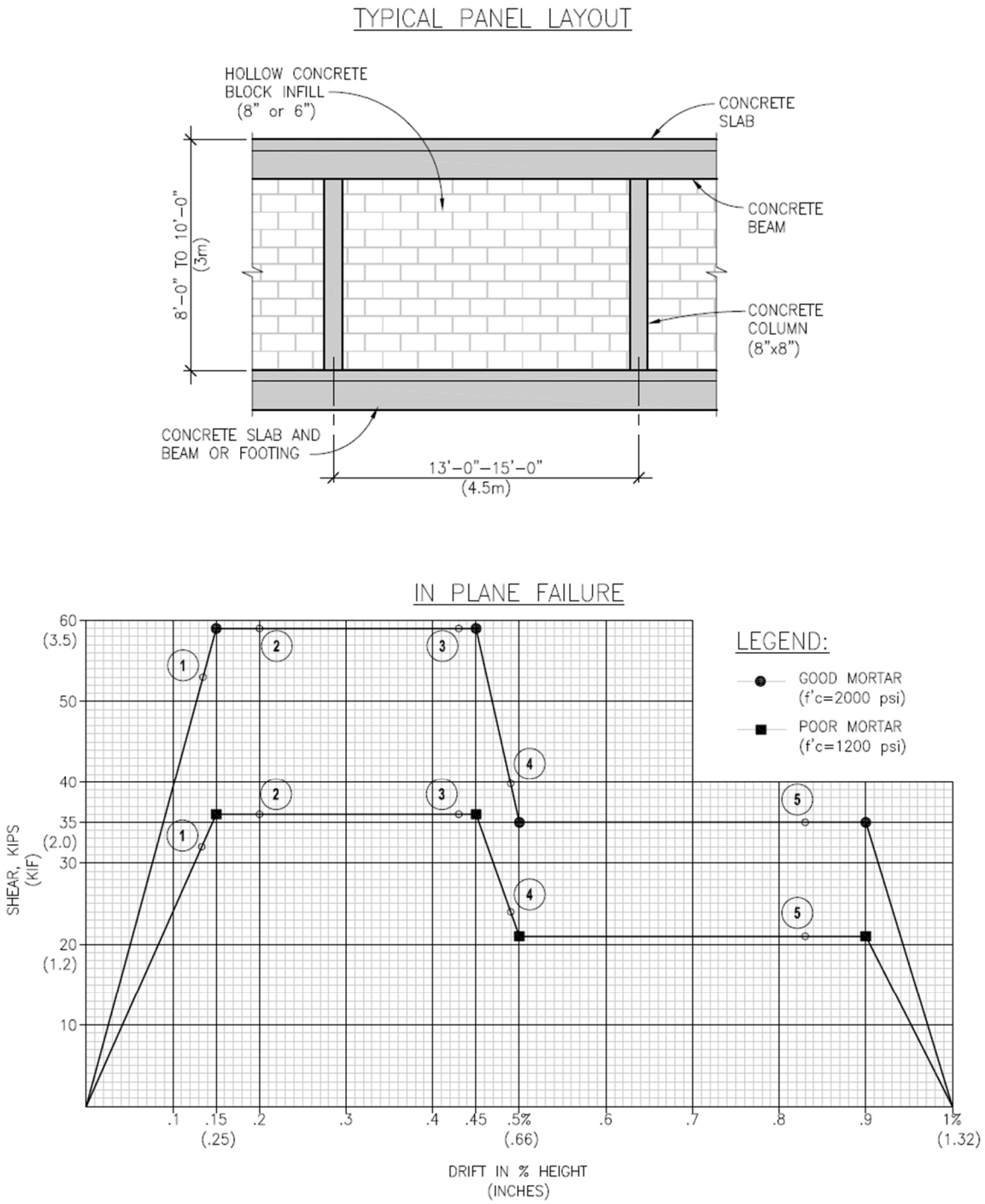
BLOCK: BLOCK HAS FALLEN OUT.
CONCRETE: COLUMNS ARE CRACKED AND SPALLED.

OCCUPANCY:

DO NOT ENTER OR OCCUPY.
STRENGTH = 10% OF PRE-EARTHQUAKE STRENGTH.

REPAIR:

DEMOLITION OF BUILDING MAY BE NECESSARY.



Based on Haitian construction hollow block infill

Figure 26: CM Evaluation Aid (credit: Lehmkuhl)

8.4 EVALUATION CHECKLIST (APPLY TO ALL INSPECTIONS – EARTHQUAKE, WIND, OR FLOOD)

- ❑ Safety Check: Identify, prioritize, and manage immediate hazards (e.g., gas leaks, downed lines, unstable debris) before approaching or entering. Use two or more people; one remains outside. Stay aware of the nearest exit at all times. Limit time spent inside damaged buildings to what the evaluation requires (NCSEA guidance). Do not enter if unsafe.
- ❑ Collapse Zone: Where collapse is a concern, keep a setback of at least 1.5 × the building height. Do not evaluate flood-damaged buildings until the water has receded.
- ❑ Exterior Inspection: Survey the entire perimeter and all accessible angles for visible damage before entry. Where plaster hides the structure, use a chipping hammer to expose the masonry-to-column joint and confirm whether the building is CM or an infill frame.
- ❑ Interior Inspection (only if exterior is safe): Examine structural components, stairwells, floors, utilities, and non-structural elements.
- ❑ Posting and Actions: Post the appropriate placard.
    - INSPECTED (Green – apparently safe)
    - RESTRICTED USE (Yellow – limited entry)
    - UNSAFE (Red – do not enter). Barricade hazardous areas if needed and recommend detailed/engineering evaluation.

8.4.1 EARTHQUAKE-SPECIFIC HAZARDS (ATC-20 FOCUS – RAPID & DETAILED)

- ❑ Overall Hazards: Building collapse, partial collapse, or significant leaning/drift/story out of plumb.
- ❑ Structural Damage: Racking of walls/frames, damage to primary connections/members, severe concrete cracking, failure of vertical/horizontal elements.
- ❑ Geotechnical: Foundation damage/off foundation, slope failure/movement, ground cracks, liquefaction signs.
- ❑ Non-structural: Parapets/ornamentation/chimneys failing, ceiling/lighting/fixed equipment hazards, broken glazing/falling hazards.
- ❑ Other: Debris impact, utilities hazards (e.g., gas/electrical).

8.4.2 WIND/FLOOD-SPECIFIC HAZARDS (ATC-45 FOCUS – WINDSTORM & FLOOD)

- ❑ Roofing: Damage, uplift, loss of covering/sheathing, sagging/buckling.

- ❑ Exterior: Wall failure/bulging, window/fenestration failure, damaged siding/cladding.
- ❑ Structural: Foundation damage from scour/erosion, frame damage/racking, overall, out-of-plumb.
- ❑ Water/Flooding: Damage to electrical/mechanical systems, water intrusion, mould signs, structural weakening from saturation.
- ❑ Site: Hazards from nearby trees/debris impact, compromised retaining walls, slope/debris flow.

Notes:

- Estimate overall damage percentage and note severe/moderate/minor levels for each category.
- Document with photos, time/date, inspector ID number (not name), and team judgment for posting.
- For combined events (e.g., hurricane with wind + flood), evaluate using both relevant sections.
- These are rapid visual checks, not substitutes for detailed engineering analysis.
- Evaluation types: a Rapid Evaluation (about 20 to 30 minutes per building) screens for obvious hazards. A Detailed Evaluation (about 30 minutes to 2 hours) is used for questionable buildings and for essential and lifeline facilities, and is where mitigation recommendations can be made. An Engineering Evaluation is a structural or geotechnical investigation by a licensed engineer.

9 Retrofitting Basics

Recommendation: In addition to repairing damaged elements, encourage seismic retrofitting to address lateral system deficiencies and significantly improve building performance in future earthquakes.

Retrofitting cannot convert an infill frame into true confined masonry, because the walls were not built before the concrete was cast against them. Strengthening an infill frame (for example with straps, dowels, or new confining elements) improves its performance, but evaluate it as an infill frame, not as CM.

Repair vs. Strengthening/Retrofit:

1. Repairs should restore elements to at least their original strength. (Figure 27, Figure 28)
2. If needed, strengthen the structure during repairs. (Figure 29, Figure 30, Figure 31)
3. For buildings beyond in-place repair or strengthening, perform full retrofits. (Figure 32)

Common Retrofit Examples:

1. Add shear walls to create a symmetrical lateral system in both directions, especially at the ground floor to reduce soft-story risks.
2. Modify infill walls to eliminate or reduce "short column" conditions.
3. Install out-of-plane connections between wood framing and brick walls, including at gable ends and roof truss/beam-to-wall connections.
4. Provide out-of-plane strength and stiffness when repairing failed parapet walls.
5. For unreinforced brick masonry buildings with wood roofs (often lacking a diaphragm), add a diaphragm using cross bracing to improve the overall lateral system.

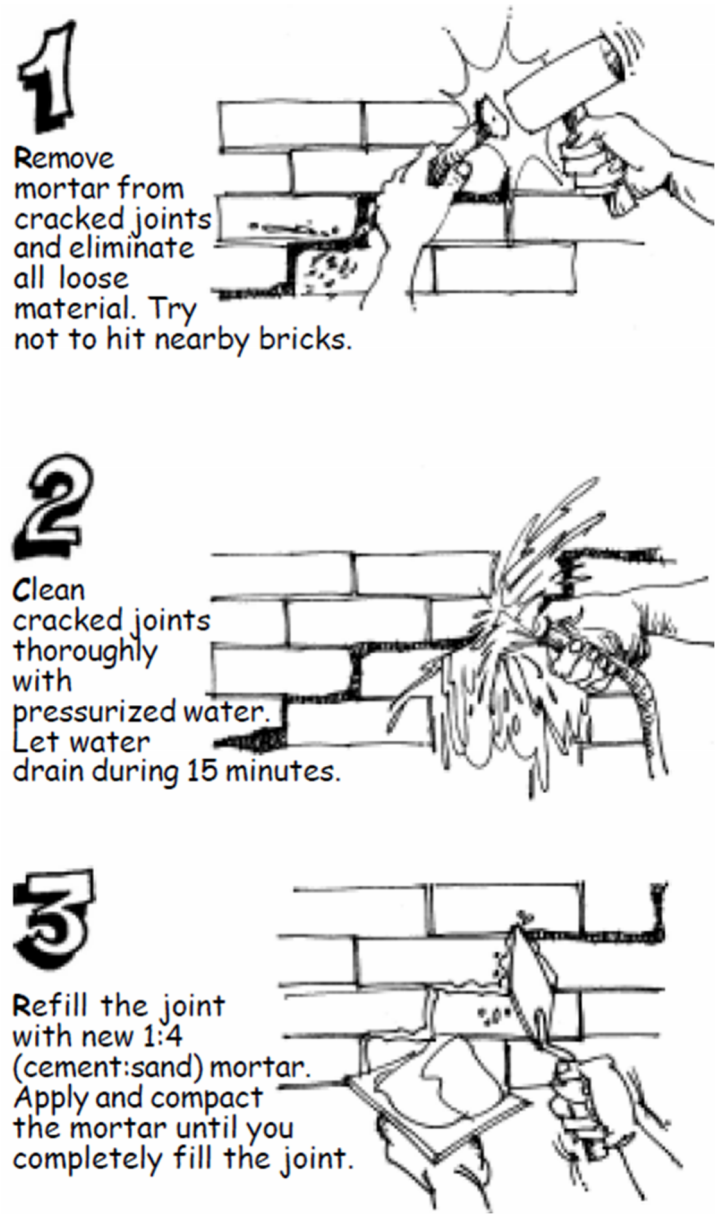


Figure 27: Repair wall cracks (credit: Blondet (ed.), Construction and Maintenance of Masonry Houses, SENCICO/PUCP, 2005)

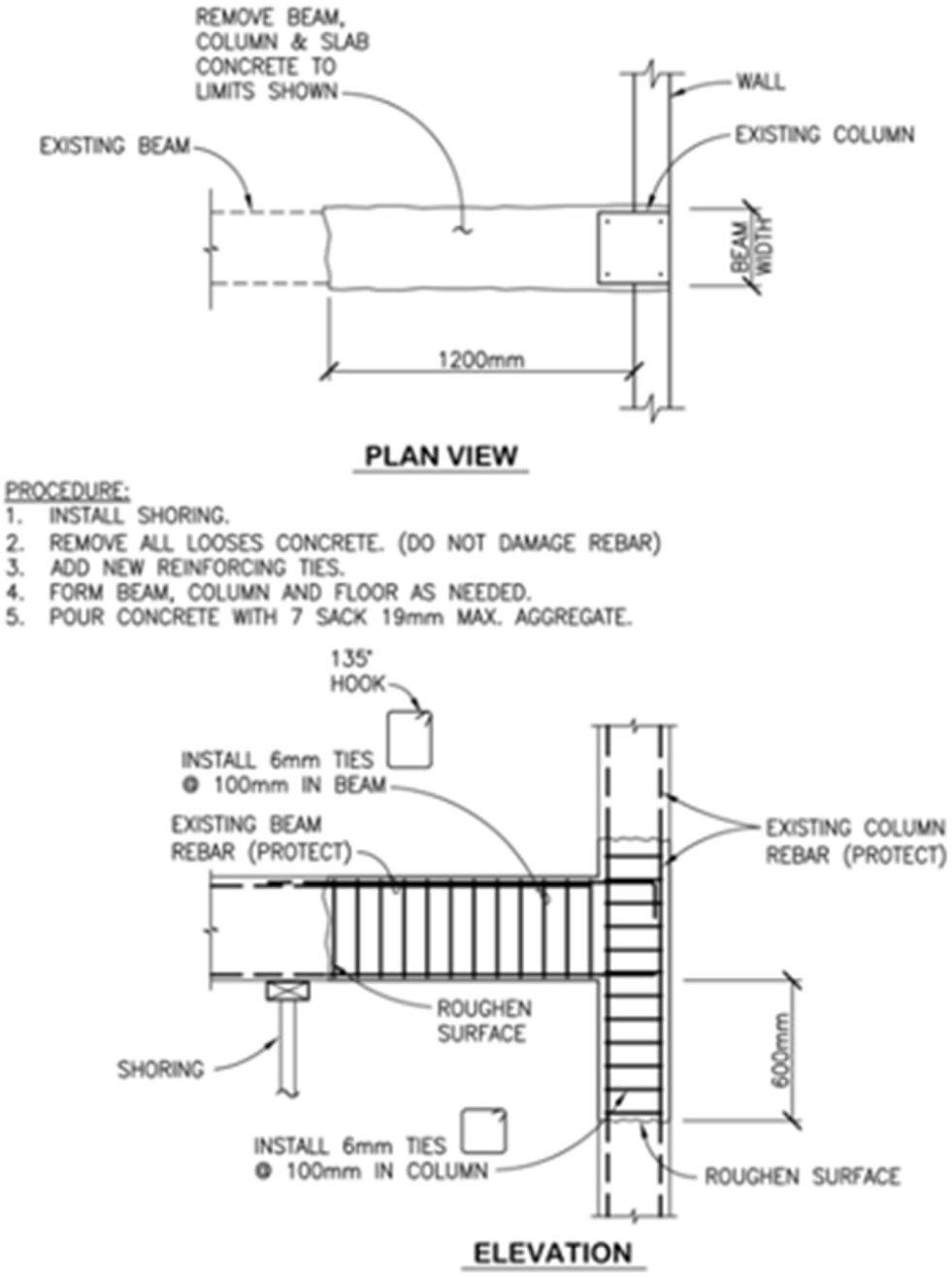


Figure 28: Column/beam repair (credit: Eric Lehmkuhl)

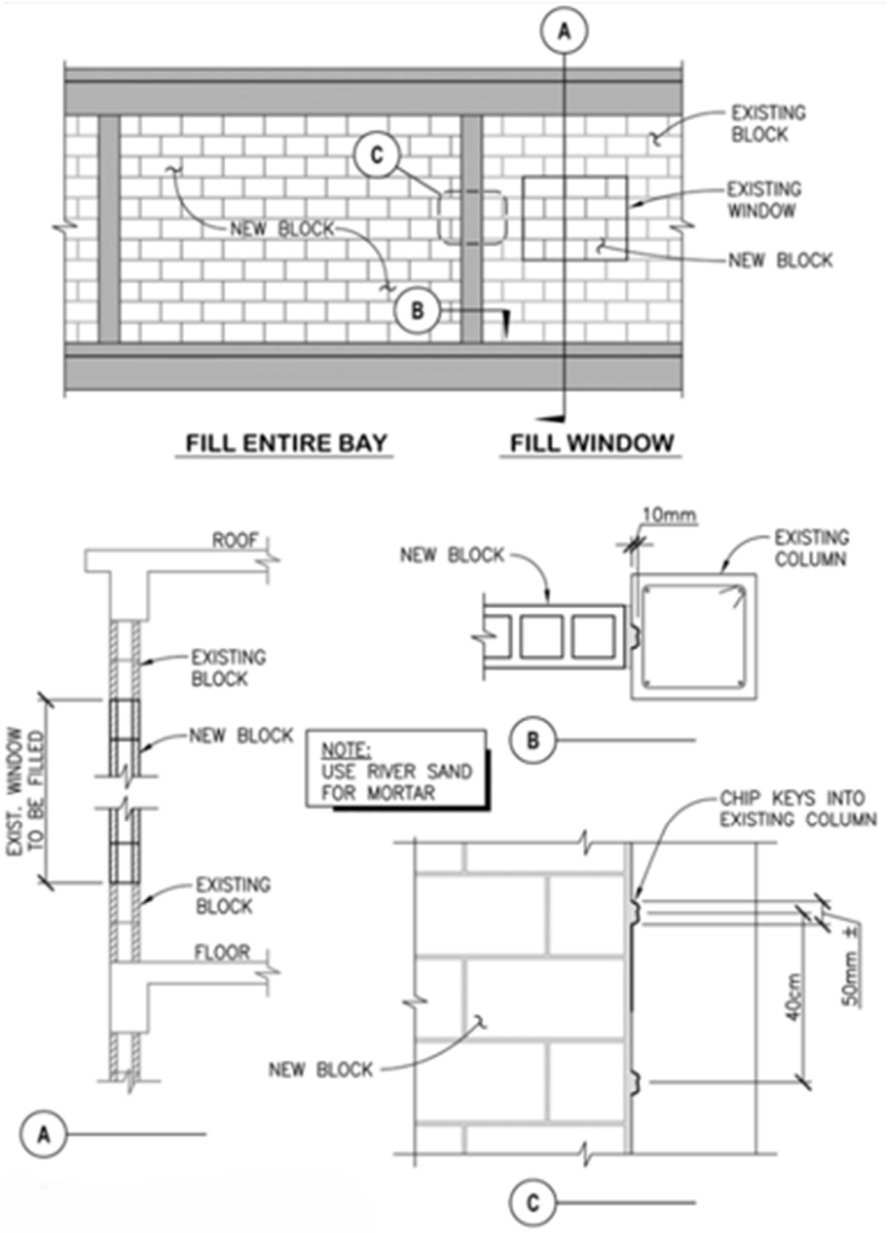


Figure 29: New infill (credit: Eric Lehmkuhl)

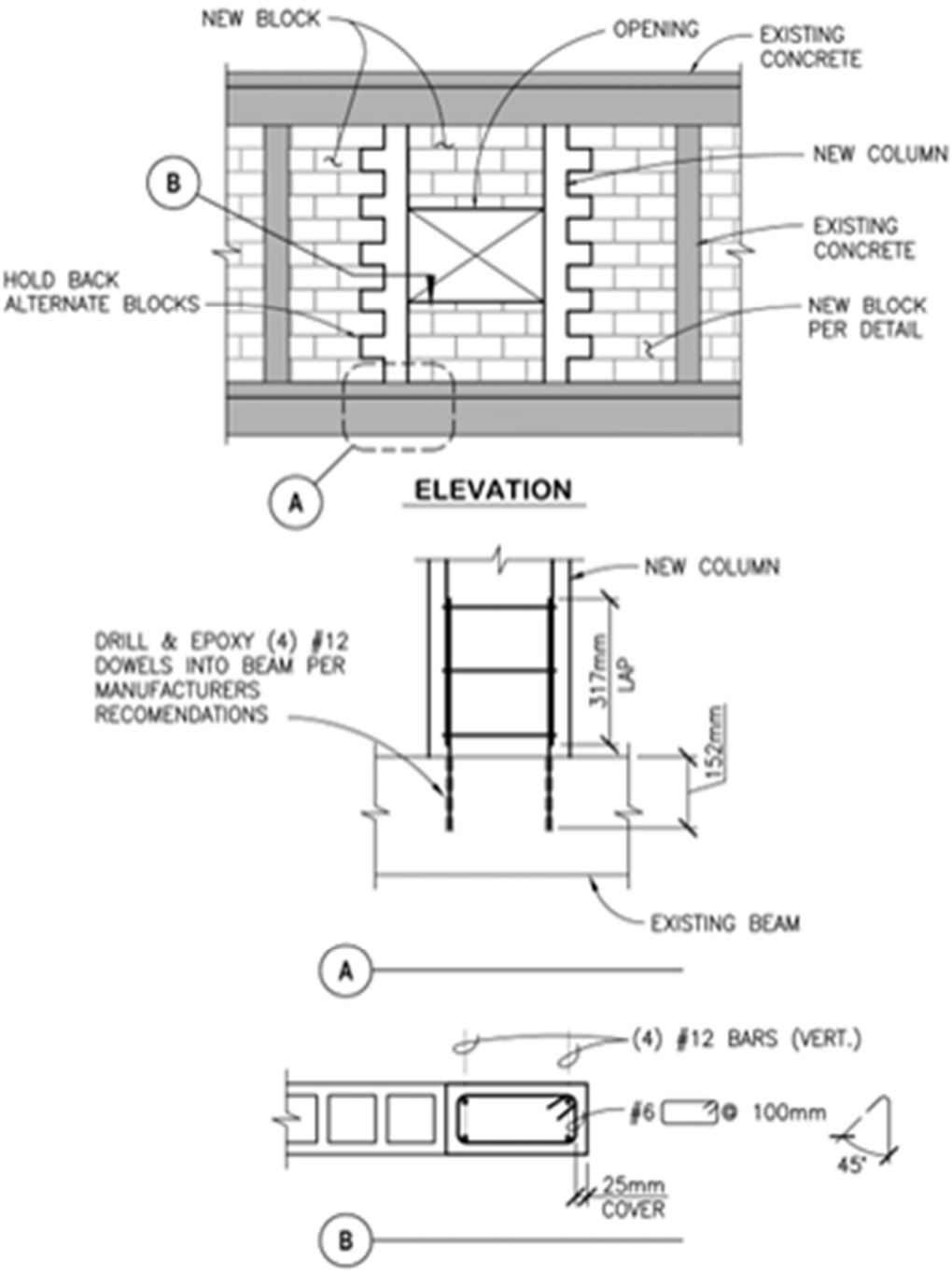


Figure 30: Shear wall with opening (credit: Eric Lehmkuhl)

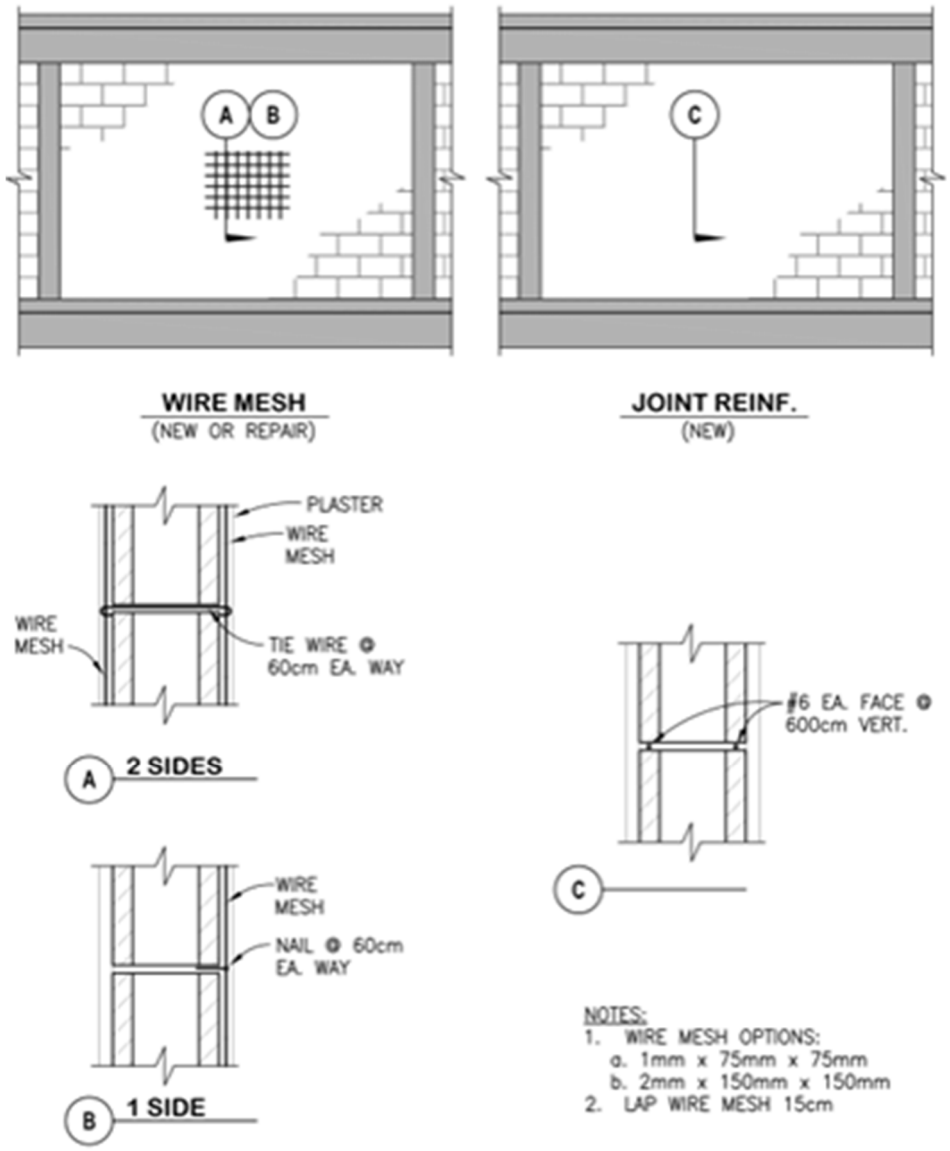
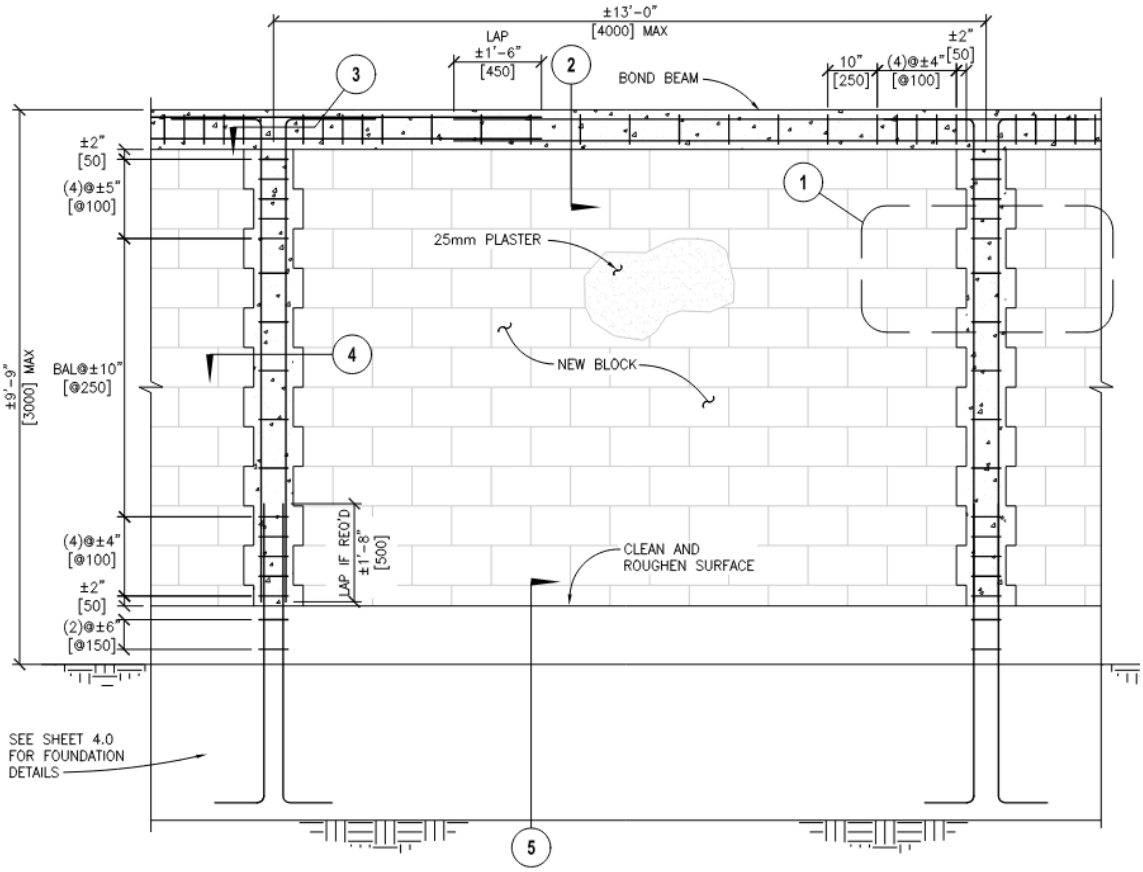
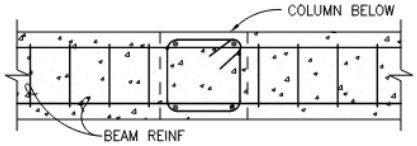


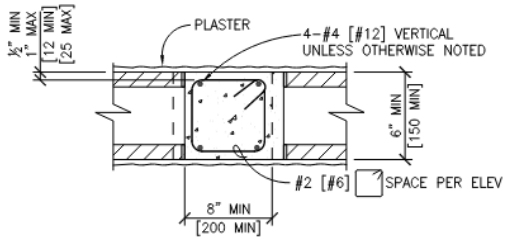
Figure 31: Shear wall reinforcement (credit: Eric Lehmkuhl)



CM WALL ELEVATION



3 PLAN AT BEAM / COLUMN



4 COLUMN SECTION

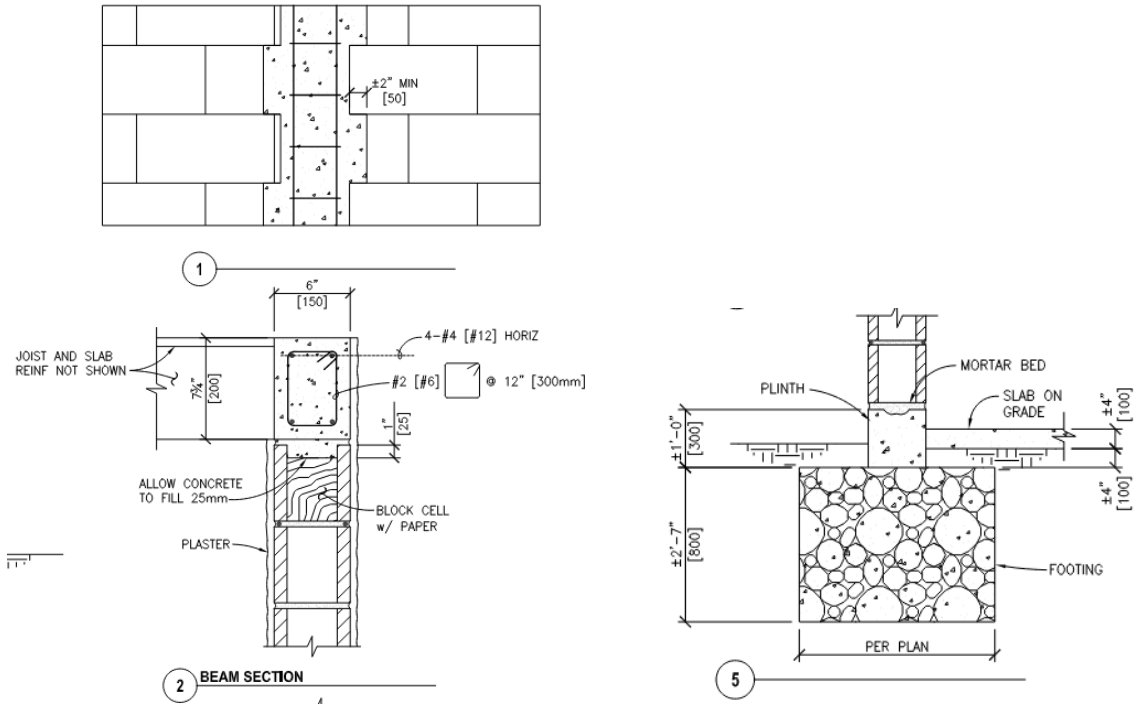


Figure 32: CM wall elevation (credit: Eric Lehmkuhl)

Appendices

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Glossary

Confined Masonry (CM): A building system in which unreinforced masonry walls are built first and reinforced concrete tie columns and ring beams are then cast against them, so that walls and confining elements act together to resist gravity and lateral loads. *See: Sections 1.1, 4.1-4.5*

Diaphragm: A horizontal structural element, typically a roof or floor, that collects lateral loads and transfers them to the vertical lateral-force-resisting elements (walls). Diaphragms are classified as flexible or rigid depending on their relative stiffness, which affects how load is distributed to the walls. *See: Sections 6.1–6.4*

Infill Frame (Masonry-Infilled RC Frame): A reinforced concrete frame built first, with masonry panels placed inside it afterwards. The masonry is connected to the frame only by mortar, or by added straps or dowels, and shares lateral load less reliably than CM. *See: Sections 1.1, 1.2, 4.1, 4.5, 8.1*

Infill Wall: A masonry wall panel constructed within a surrounding frame. The wall may contribute to structural resistance even when not intended as the primary lateral-force-resisting system. *See: Sections 1.1, 4.4, 4.5*

Keyed Connection: Also called toothing, a wall-to-concrete interface created by staggered masonry units or other mechanical interlocking details that improve force transfer and reduce separation between materials. *See: Section 4.5*

Out-of-Plane Failure: Failure of a wall by bending or displacement perpendicular to its surface, often resulting in partial or complete wall collapse. *See: Sections 4.1, 4.5, 6.5, 8.2, 9*

Peak Ground Acceleration (PGA): A measure of the maximum ground acceleration expected during an earthquake at a given location, often used to estimate design seismic forces. *See: Sections 5.2, 5.3.1 Seismic Loads*

Plinth Beam: A horizontal reinforced concrete beam located at or near ground level that ties walls and columns together above the foundation. *See: Section 3.3*

Ring Beam: A horizontal reinforced concrete element that confines masonry walls and ties the structure together at foundation, floor, roof, or opening levels. *See: Section 4.3*

Short Column: A column whose effective height is reduced by adjacent walls, openings, or infill, resulting in higher shear demands and greater earthquake vulnerability. *See: Section 9*

Soft Story: A building level that is significantly weaker or more flexible than adjacent stories, making it vulnerable to concentrated earthquake damage or collapse. *See: Sections 3.1, 8.2, 9*

Tie Column: A vertical reinforced-concrete element constructed at wall intersections, corners, and other locations to confine masonry wall panels and improve structural performance. *See: Section 4.2*

Wall Density Method (WDM): A simplified procedure for evaluating seismic adequacy by comparing the amount of effective masonry wall area to the floor or roof area supported by the building. *See: Section 5.1*

Wall Density Index (WDI): The numerical ratio used in the Wall Density Method, the target Wall Density based on local ground acceleration and soil conditions, calculated by dividing effective wall area by supported floor or roof area. *See: Section 5.1*

Assessment Forms

ATC-20 Rapid Evaluation Safety Assessment Form

Inspection

Inspector ID: _____ Inspection date and time: _____ ☐ AM ☐ PM

Affiliation: _____ Areas inspected: ☐ Exterior only ☐ Exterior and interior

Building Description

Building name: _____

Address: _____

_____

Building contact/phone: _____

Number of stories above ground: _____ below ground: _____

Approx. "Footprint area" (square feet): _____

Number of residential units: _____

Number of residential units not habitable: _____

Type of Construction

☐ Wood frame ☐ Concrete shear wall

☐ Steel frame ☐ Unreinforced masonry

☐ Tilt-up concrete ☐ Reinforced masonry

☐ Concrete frame ☐ Other: _____

Primary Occupancy

☐ Dwelling ☐ Commercial ☐ Government

☐ Other residential ☐ Offices ☐ Historic

☐ Public assembly ☐ Industrial ☐ School

☐ Emergency services ☐ Other: _____

Evaluation

Investigate the building for the conditions below and check the appropriate column.

Observed Conditions:	Minor/None	Moderate	Severe
Collapse, partial collapse, or building off foundation	☐	☐	☐
Building or story leaning	☐	☐	☐
Racking damage to walls, other structural damage	☐	☐	☐
Chimney, parapet, or other falling hazard	☐	☐	☐
Ground slope movement or cracking	☐	☐	☐
Other (specify) _____	☐	☐	☐

Estimated Building Damage (excluding contents)

☐ None

☐ 0–1%

☐ 1–10%

☐ 10–30%

☐ 30–60%

☐ 60–100%

☐ 100%

Comments: _____

_____

Posting

Choose a posting based on the evaluation and team judgment. *Severe* conditions endangering the overall building are grounds for an Unsafe posting. Localized *Severe* and overall *Moderate* conditions may allow a Restricted Use posting. Post INSPECTED placard at main entrance. Post RESTRICTED USE and UNSAFE placards at all entrances.

☐ **INSPECTED** (Green placard) ☐ **RESTRICTED USE** (Yellow placard) ☐ **UNSAFE** (Red placard)

Record any use and entry restrictions exactly as written on placard: _____

_____

_____

Further Actions

Check the boxes below only if further actions are needed.

☐ Barricades needed in the following areas: _____

_____

☐ Detailed Evaluation recommended: ☐ Structural ☐ Geotechnical ☐ Other: _____

☐ Other recommendations: _____

Comments: _____

_____

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ATC-20 Detailed Evaluation Safety Assessment Form

Inspection

Inspector ID: _____

Affiliation: _____

Inspection date and time: _____ ☐ AM ☐ PM

Final Posting
from page 2

☐ Inspected
☐ Restricted Use
☐ Unsafe

Building Description

Building name: _____

Address: _____

_____

Building contact/phone: _____

Number of stories above ground: _____ below ground: _____

Approx. "Footprint area" (square feet): _____

Number of residential units: _____

Number of residential units not habitable: _____

Type of Construction

☐ Wood frame
☐ Steel frame
☐ Tilt-up concrete
☐ Concrete frame
☐ Concrete shear wall
☐ Unreinforced masonry
☐ Reinforced masonry
☐ Other: _____

Primary Occupancy

☐ Dwelling
☐ Other residential
☐ Public assembly
☐ Emergency services
☐ Commercial
☐ Offices
☐ Industrial
☐ Other: _____
☐ Government
☐ Historic
☐ School

Evaluation

Investigate the building for the conditions below and check the appropriate column. There is room on the second page for a sketch.

	Minor/None	Moderate	Severe	Comments
Overall hazards:				
Collapse or partial collapse	☐	☐	☐	_____
Building or story leaning	☐	☐	☐	_____
Other _____	☐	☐	☐	_____
Structural hazards:				
Foundations	☐	☐	☐	_____
Roofs, floors (vertical loads)	☐	☐	☐	_____
Columns, pilasters, corbels	☐	☐	☐	_____
Diaphragms, horizontal bracing	☐	☐	☐	_____
Walls, vertical bracing	☐	☐	☐	_____
Precast connections	☐	☐	☐	_____
Other _____	☐	☐	☐	_____
Nonstructural hazards:				
Parapets, ornamentation	☐	☐	☐	_____
Cladding, glazing	☐	☐	☐	_____
Ceilings, light fixtures	☐	☐	☐	_____
Interior walls, partitions	☐	☐	☐	_____
Elevators	☐	☐	☐	_____
Stairs, exits	☐	☐	☐	_____
Electric, gas	☐	☐	☐	_____
Other _____	☐	☐	☐	_____
Geotechnical hazards:				
Slope failure, debris	☐	☐	☐	_____
Ground movement, fissures	☐	☐	☐	_____
Other _____	☐	☐	☐	_____

General Comments: _____

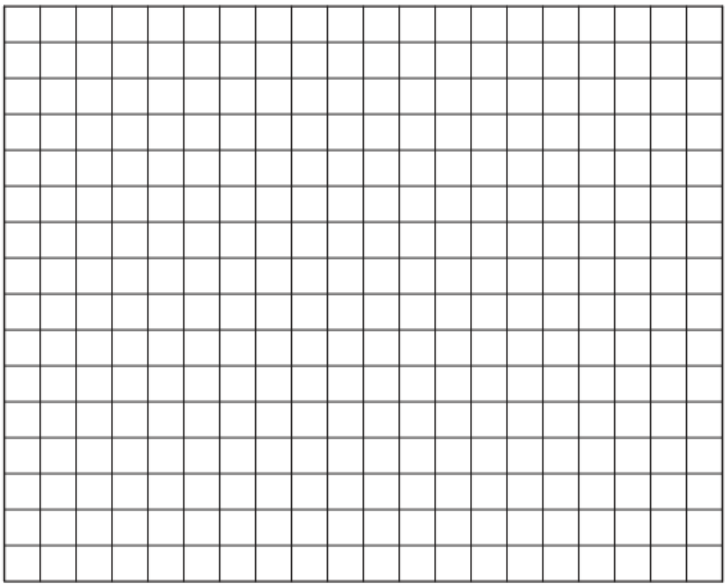
_____

Continue on page 2

ATC-20 Detailed Evaluation Safety Assessment Form — Page 2

Building name: _____ Inspector ID: _____

Sketch (optional)
Provide a sketch of the building or damaged portions. Indicate damage points.



Estimated Building Damage
If requested by the jurisdiction, estimate building damage (repair cost ÷ replacement cost, excluding contents).

- ☐ None
- ☐ 0–1%
- ☐ 1–10%
- ☐ 10–30%
- ☐ 30–60%
- ☐ 60–100%
- ☐ 100%

Posting
If there is an existing posting from a previous evaluation, check the appropriate box.

Previous posting: ☐ INSPECTED ☐ RESTRICTED USE ☐ UNSAFE Inspector ID: _____ Date: _____

If necessary, revise the posting based on the new evaluation and team judgment. *Severe* conditions endangering the overall building are grounds for an Unsafe posting. Local *Severe* and overall *Moderate* conditions may allow a Restricted Use posting. Indicate the current posting below and at the top of page one.

☐ **INSPECTED** (Green placard) ☐ **RESTRICTED USE** (Yellow placard) ☐ **UNSAFE** (Red placard)

Record any use and entry restrictions exactly as written on placard: _____

_____

_____

Further Actions Check the boxes below only if further actions are needed.

☐ Barricades needed in the following areas: _____

_____

☐ Engineering Evaluation recommended: ☐ Structural ☐ Geotechnical ☐ Other: _____

☐ Other recommendations: _____

_____

_____

Comments: _____

_____

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DISASTER RESPONSE
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Building Assessment Report

(insert city initial here)-001

Building Name:	(insert google map pin drop image here)
GPS Coordinates:	
Assessment Date & Time:	
Type of Construction:	
Building Occupancy:	
Construction Date:	

(insert front elevation photo here)

Damage Observations:

Recommendations:

Additional Photos: