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Editorial

This issue is devoted to disseminating a very important new publication on confined masonry. Given that confined masonry performs much better than RC frame infills or unreinforced masonry construction in earthquakes, this superior method of building needs to be widely introduced. Selected sections of the “Construction Guide for Low-Rise Confined Masonry Buildings” prepared by Tom Schacher and Tim Hart therefore comprise this issue. Readers are encouraged to download this Confined Masonry Network publication and become acquainted with all aspects of constructing low-rise confined masonry buildings.

Introduction to “Construction Guide for Low-Rise Confined Masonry Buildings”

In most countries modern low-rise residential construction is made either of unreinforced masonry or reinforced concrete moment frames with masonry infill walls. Experience has shown that both systems can be significantly affected by earthquakes. Unreinforced masonry buildings cannot deal adequately with horizontal forces, while reinforced concrete frames are difficult to build correctly. Too many details have to be observed and properly implemented, a challenge beyond the capabilities of self-builders or workers with no formal training. A simpler and more forgiving construction technology is needed to ensure safe construction.

Confined masonry combines elements of both systems, but it is a simple and forgiving construction method which has demonstrated good performance in past damaging earthquakes in Latin America. It is widely practiced in Latin America and Mediterranean Europe, and it has been the subject of lab testing and research studies, and has been incorporated in national building codes. In some

Asian countries, such as Indonesia and China, confined masonry is regarded as a standard construction technique, while on the Indian subcontinent confined masonry has been actively promoted over the last decade.

As confined masonry is a construction system that has been developed by practitioners in various countries in parallel, there is a lack of uniform rules on how it should be implemented correctly. In 2008 the Confined Masonry Network decided to tackle this issue by compiling a set of common rules from the various existing codes and guidelines on confined masonry and use them to develop a uniform set of guidelines.

A first result has been the Seismic Design Guide for Low-Rise Confined Masonry Buildings, published by the Network in 2011, which provides prescriptive design provisions for engineers who want to use this construction system.

The present Construction Guideline for Low-Rise Confined Masonry Buildings addresses the needs of small-scale contractors, technicians, government staff, architects as well as non-governmental organizations involved in post-disaster reconstruction. The guide has been written with users with various professional backgrounds in mind, including a workforce with little formal training. As a consequence this guide not only shows the practical detailing of confined masonry construction, but also offers a wealth of basic information on good construction practices in general.

A note of caution: this guide explains how to build earthquake resistant houses with a maximum height of two stories (ground floor and upper floor). For taller buildings an experienced engineer must be consulted for specific calculations!

Finally, a third volume entitled Engineered Guidelines for Confined Masonry is under development and will be made available in 2016.

A Summary of “Construction Guide for Low-Rise Confined Masonry Buildings”

prepared by Tom Schacher (Switzerland) and Tim Hart (USA). *Confined Masonry Network*, October 2015.

PART I: GENERAL ASPECTS OF CONFINED MASONRY CONSTRUCTION

Why use confined masonry?

Confined masonry construction has been used during the last half century in various parts of the world. Researchers in Latin American and European countries have studied its behavior and refined the technique, and governments have promoted its application with very satisfactory results. The severe 2010 earthquake in Chile (M 8.8) caused a relatively low number of victims, in part due to the wide use of confined masonry construction for single family and apartment housing.

Before going into the details of confined masonry construction, it is worthwhile to look at the two of the most common construction methods used for low-rise housing. They are unreinforced masonry and reinforced concrete frames with infill walls. It is important to understand their weak points which can be avoided by employing the confined masonry construction technology.

Unreinforced masonry in earthquake prone areas

Unreinforced masonry works well in areas with no earthquakes because masonry is strong in compression and the walls only have to bear vertical loads. In addition, masonry construction provides thermal comfort and durability. However, in earthquake-prone areas, horizontal loads due to earthquake shaking must be taken into account. Unreinforced masonry walls have some strength to resist lateral forces. However, it's limited and once it's exceeded the walls degrade rapidly, never to recover, like a stack of books on a wobbly table (Figure 1).

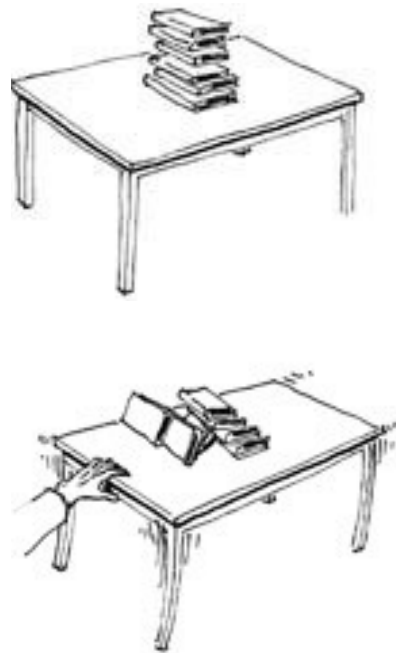


Figure 1: Stack of books not attached together will fall apart when the table gets shaken

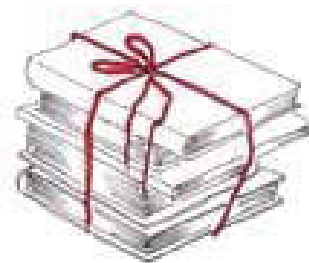
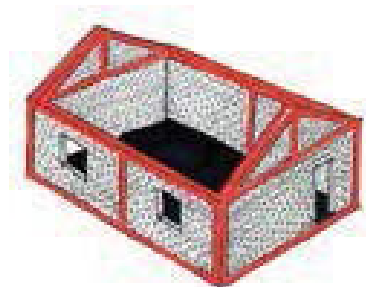


Figure 2: Reinforced concrete ties hold the house together like a string around a stack of books



In a building where walls are not well-connected to the floors and roof by reinforcing or confining elements, the walls will separate at the corners and the structure will undergo serious damage or collapse.

When unreinforced masonry is confined by concrete tie elements, however, it greatly slows down the degradation of the walls. Similar to a pile of books held together by a string, the books will still slide around but the string prevents the stack from falling apart. That's exactly what confined masonry is doing by holding all elements together with reinforced concrete ties (Figure 2).

Reinforced Concrete frames with infill walls in earthquake prone areas

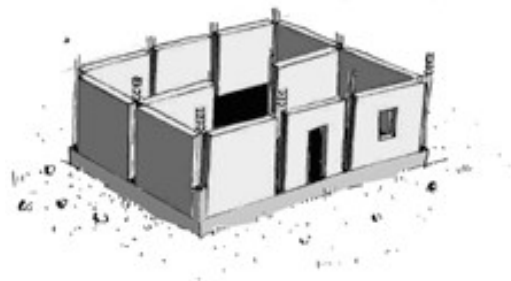
In confined masonry the masonry walls are built first, and then concrete vertical and horizontal ties are poured around them. By contrast, in framed infill construction the concrete is poured first, then the masonry infill is placed (Figure 3).

Reinforced concrete (RC) frame structures with infill walls are much more complex to build than they appear to the common worker. Concrete is not simply 'a glue' that holds everything together. Instead, the concrete frame is the primary force resisting element. The masonry is placed after the concrete and is assumed to act as a non-load bearing partition. Because the concrete is the seismic load resisting element, special detailing is needed in the frame. This special detailing makes reinforced concrete frames very sensitive to implementation errors which can be fatal under earthquake conditions. A whole series of steps must be made properly:

- the rebar has to be placed in exactly the right position,
- there must be enough space around the rebars to allow for sufficient concrete cover,
- rebar connection details must be correct,
- concrete has to be made in the right proportions and has to be mixed perfectly,

- pouring of concrete and its compaction must be done to a high standard (very difficult to achieve without a needle vibrator),
- curing must be done properly to ensure correct hardening of the concrete.

The stress in the concrete moment frame members is high because the infill masonry is assumed not to contribute any strength to the wall. All vertical and horizontal loads have to go through the frame and its relatively narrow joints. Thus, there is no space for error!



Confined masonry: walls first, concrete ties later



RC frames with infill walls: concrete frame first, walls later

Figure 3: Inverse construction sequence in confined masonry compared to RC frames with infill walls

The second problem with reinforced concrete frames is that the frames in themselves do not complete a building. A house needs walls. Yet, by putting walls in between the reinforced concrete columns, it doesn't allow for the frames to move freely as is often assumed by many engineers. This problem can be solved with special detailing, but the solutions may be too complex to be used by simple builders in poor countries.

Finally, infill walls are very difficult to hold back against out-of-plane loads (earthquake acceleration in the direction perpendicular to the walls). Infill walls can fall out of frames and can endanger people's safety (Figure 4).

Finished RC frames with infill walls and confined masonry buildings look very similar. However, these two systems have very different structural behavior when subjected

Figure 4: Walls tend to fall out of their RC frames

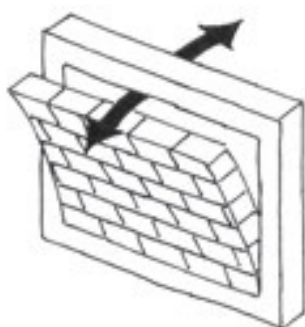


Figure 5: Confined elements called ties hold the walls together like a string

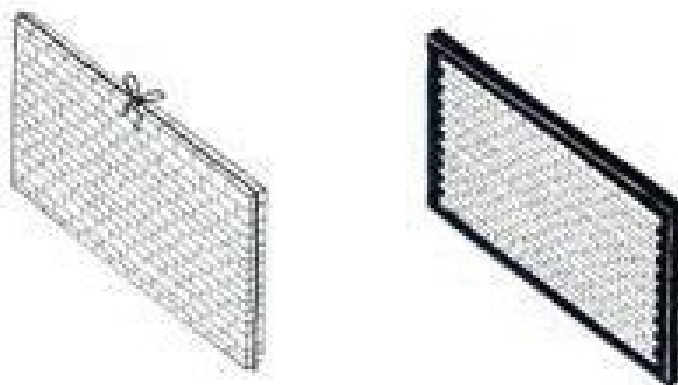
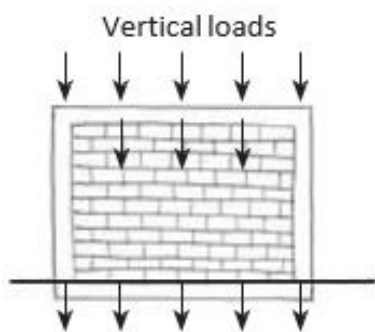
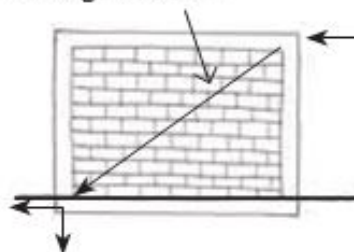


Figure 6: In the confined masonry system, load paths are simple



Horizontal loads are brought to the ground through the wall



to lateral loads. In a RC frame system the load path is complex and all forces have to be carried by beams and columns and beam-column joints, while the load path in a confined masonry system is simple and straightforward because the forces are carried to the ground by the walls; it is a load-bearing wall system.

Confined Masonry Basics

In the confined masonry system the walls carry all the vertical and horizontal loads. Walls are held together by reinforced concrete confining elements that improve the in-plane strength of these masonry walls, resisting the shear forces induced by an earthquake (Figure 5).

While detailing of rebar connections must still be correct, in particular the lap lengths, confined masonry structures are more tolerant of bad execution (Figure 6). If the concrete in the reinforced concrete ties is less than perfect, the system still works. However, the better the execution, the stronger the building!

Main components of a confined masonry building

The shape of a building plan and the structural elements of a building influence earthquake performance. The following rules in Figure 7 apply to most construction technologies and building sizes.

The main characteristics of a confined masonry building at a glance

Slab:

Slabs distribute earthquake loads to all the walls. They have to be well connected with the walls by means of horizontal and vertical ties.

Horizontal and vertical ties:

The vertical ties (“tie-columns”) are the vertical confining concrete elements of the walls. The horizontal ties (Plinths and ring beams) are the confining concrete elements above and below the walls. All ties must be securely fastened to one another.

Solid walls:

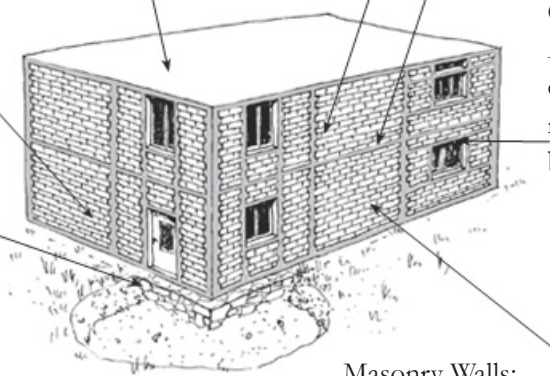
Each facade should contain at least one solid wall panel without openings.

Openings:

All openings must be confined. Openings should not be too large and should be well distributed.

Foundation:

Foundations must be continuous to support the loads transferred to the ground by the walls.



Masonry Walls:

Walls are the most important elements in a confined masonry structure. They transmit all vertical and horizontal forces to the ground. Walls may be built using various masonry units of adequate quality and strength. Walls must be well distributed though the building plan.

Figure 7: Main elements of a confined masonry building

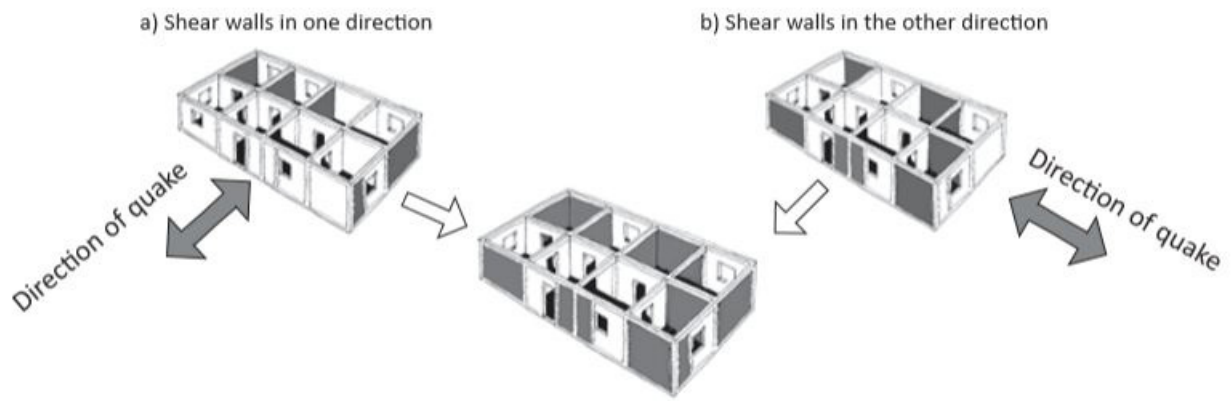


Figure 8: Amount, proportions and position of shear walls

Walls

The essence of the confined masonry system lies in the strength of its walls which bear all vertical (gravity) and horizontal (earthquake) loads. For the walls to be able to do that, they need to be confined with reinforced concrete elements, must not have any openings and should be at least as long as they are high. It's these shear walls which will ensure the earthquake resistance of a building (Figure 8).

A sufficient number of confined masonry walls without openings must be placed in each direction and should be distributed as evenly as possible over the floor layout. For how to calculate the exact number of walls, please see the appendices.

- Each facade needs at least one solid wall panel
- A confined wall panel can only be used as a shear wall if its length is more than two thirds of its height.

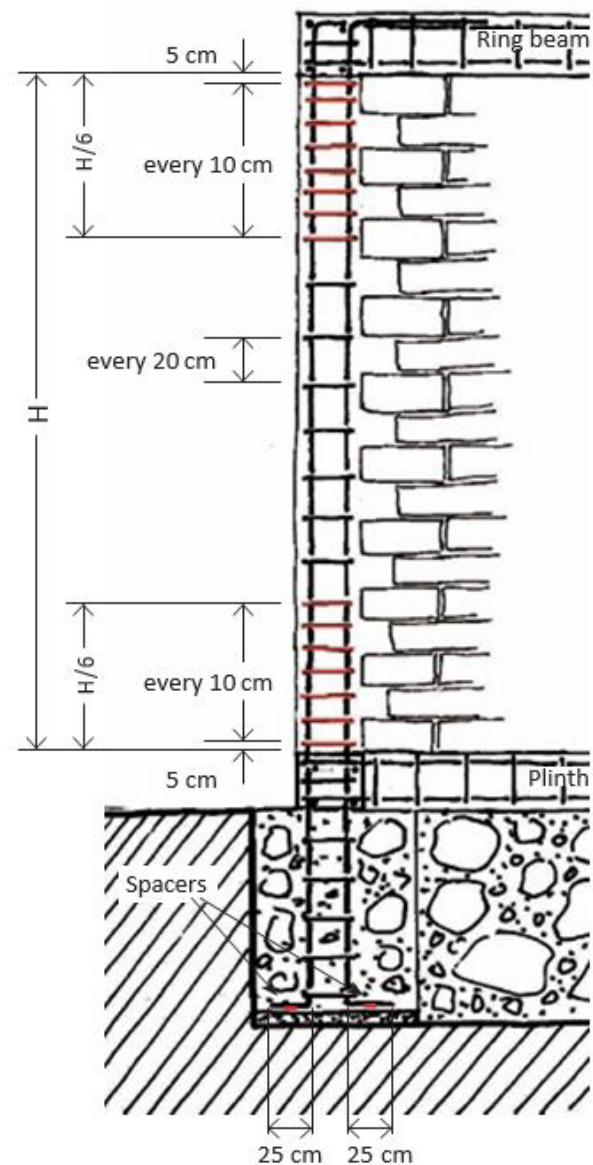


Figure 9: Stirrup spacing on vertical ties

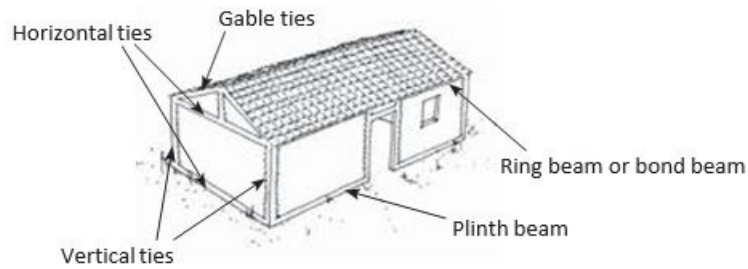


Figure 10: Position and naming of horizontal and vertical ties

Vertical and horizontal tie reinforcements

Vertical and horizontal RC ties are the essence of confined masonry. They confine the wall element, making them more resistant to earthquake forces (Figure 10).

Vertical ties ("tie columns")

The armature of the vertical ties starts at the very bottom of the foundation.

The minimum number of lengthwise rebars is four (vertical ties with only 3 rebars are not permissible).

The minimum cross section of vertical ties is 15 x 15 cm

but only if stirrups bent at 1 % (type 2, see next page) are used.

With normal stirrups (type 1 with 45° hooks) the minimum cross section is 20 x 20 cm (Figure 9).

Diameters of rebars:

Minimum diameter for lengthwise (i.e. vertical) reinforcement bars is 10 mm (3/8"). Rebars have to be deformed. If deformed steel cannot be found, the minimum diameter must be increased to 12 mm (1/2").

Stirrup diameter is 6 mm (1/4"). Rebars can be smooth (Figure 11).

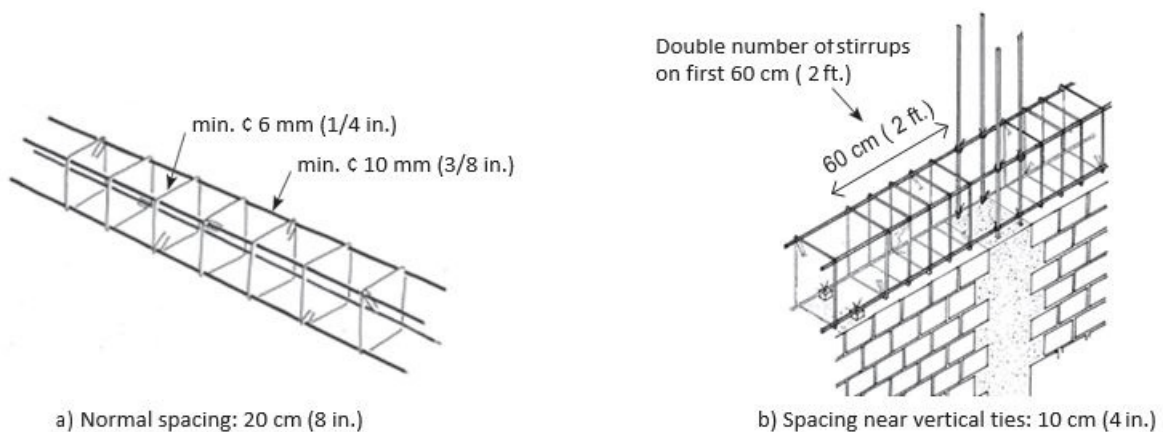


Figure 11: Diameter of rebars and spacing of stirrups



Figure 12: Construction Photographs

Spacing:

Stirrups are spaced every 20 cm except for the first and last sixth of the height ($H/6$) where they are doubled, resulting in a spacing of 10 cm. The first stirrup above the plinth and the last stirrup below the bond beam should be placed at 5 cm.

Note: The ties that encase the vertical reinforcement are referred to here as “stirrups” in order to differentiate them from the concrete elements that are referred to as “ties”. These “stirrups” are often called ties.

Horizontal ties (plinth and ring beams)

The plinth beam is the horizontal reinforced concrete (RC) tie placed between the foundation and the wall. It is one of the four basic confining elements that hold a wall together. The ring or bond beam is the horizontal RC tie placed on top of a wall. They both must be well connected with the vertical ties.

For the diameters of the rebars and their spacing the same rules apply as with vertical ties. Note: the number of stirrups near to the vertical ties should be doubled, resulting in a spacing of 10 cm (4 in.) between each other (Figure 9).

With regard to the form, type 1 stirrups with 45° hooks should be used everywhere.

Construction photographs are shown in Figure 12.

Earthquake Hazard Centre Promoting Earthquake-Resistant Construction in Developing Countries

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