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EFFECT OF EARTHQUAKE ON CONFINED MASONRY CONSTRUCTION

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Abstract: *In many developing countries, masonry is used for housing because of its low material cost and simplicity of construction. Most of the masonry buildings have been constructed to be unreinforced masonry. However the earthquake shaking can easily render an unreinforced masonry building. For many years now, reinforced concrete frame construction has also been very popular. In this type of construction, builders add unreinforced masonry walls after they construct the rein-forced concrete frame. Reinforced concrete frame construction might seem a better solution to resist earthquakes than unreinforced masonry. Unfortunately, these frames require a high degree of skill to build properly. Typically, concrete frame buildings with masonry infills perform very poorly when subjected to strong ground shaking, as do buildings of unreinforced brick masonry. An alternative construction technology, using the same construction materials, is Confined Masonry construction. Confined masonry is a construction system where the masonry walls are built first, and the concrete columns and beams are poured in afterwards to enclose (confine) the wall. It has typically performed well in past earthquakes worldwide, when built according to code requirements. Its satisfactory earthquake performance is due to the joint action of masonry walls and their confining. This paper attempt to address the knowledge about confined masonry, its worldwide application and resistance behavior to earthquakes.*

Keywords: *Confined masonry, Unreinforced Masonry, Earthquake resistance.*

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INTRODUCTION

Over the past 25 years, hundreds of thousands of people all around the globe have been needlessly killed by the collapse of their own homes during earthquakes. Typically, concrete frame buildings with masonry infills perform very poorly when subjected to strong ground shaking, as do buildings of unreinforced brick masonry. An alternative construction technology, using the same construction materials, is CONFINED MASONRY construction. Confined masonry is a construction system where the masonry walls are built first, and the concrete columns and beams are poured in afterwards to enclose (confine) the wall. It has typically performed well in past earthquakes worldwide, when built according to code requirements. Its satisfactory earthquake performance is due to the joint action of masonry walls and their confining.

In many developing countries, masonry is used for housing because of its low material cost and simplicity of construction. Masonry is a sturdy and durable material for wind and vertical loads that houses must routinely withstand. However, if it is unreinforced, earthquake shaking can easily render a masonry building. For many years now, reinforced concrete frame construction has also been very popular. In this type of construction, builders add unreinforced masonry walls after they construct the rein-forced concrete frame. Reinforced concrete frame construction might seem a better solution to resist earthquakes than unreinforced masonry. Unfortunately, these frames require a high degree of skill to build properly. The interaction of the unreinforced masonry infills with the frames causes brittle behavior that is only, at best, marginally better than unreinforced masonry construction.

Given the universal popularity of masonry and the widespread availability of cement, reinforcing steel, and aggregate, confined masonry is a simple solution. By making some inexpensive and easy changes to traditional construction materials and procedures, the risk of casualties can be significantly reduced.

CONFINED MASONRY CONSTRUCTION

Over the last 100 years, confined masonry construction has emerged as a building technology that offers an alternative to both unreinforced masonry and RC frame construction. In fact, confined masonry has features of both these technologies. Confined masonry construction consists of masonry walls (made either of clay brick or concrete block units) and horizontal and vertical RC *confining members* built on all four sides of a masonry wall panel. Vertical members, called *tie-columns* or *practical columns*, resemble columns in RC frame construction except that they tend to be of far smaller cross-section. Horizontal elements, called *tie-beams*, resemble beams in RC frame construction.

The confining members are effective in

1. Enhancing the stability and integrity of masonry walls for in-plane and out-of-plane earthquake forces (confining members can effectively contain damaged masonry wall
2. Enhancing the strength (resistance) of masonry walls under lateral earthquake loads
3.Reducing the brittleness of masonry walls under earthquake loads and hence improving their earthquake performance.

The structural components of a confined masonry building are (see Figure 1):
Masonry walls – transmit the gravity load from the slab(s) above down to the foundation; the walls act as bracing panels, which resist horizontal earthquake forces. The walls must be confined by concrete tie-beams and tie-columns to ensure satisfactory earthquake performance.
Confining elements (tie-columns and tie-beams) – provide restraint to masonry walls and protect them from complete disintegration even in major earthquakes; these elements resist gravity loads and have important role in ensuring vertical stability of building in an earthquake.
Floor and roof slabs – transmit both gravity and lateral loads to the walls. In an earthquake, slabs behave like horizontal beams and are called diaphragms.
Plinth band – transmits the load from the walls down to the foundation. It also protects the ground floor walls from excessive settlement in soft soil conditions.
It should be noted that the term “confined masonry” is used in a general sense for different forms of masonry construction reinforced with additional steel, timber, or concrete elements. However, the focus of this document is on clay brick or concrete block masonry walls “confined” with reinforced concrete tie-beams and tie-columns.
Confined masonry construction is somewhat similar to reinforced masonry. In reinforced masonry, vertical and horizontal reinforcement bars are provided to enhance the strength of masonry walls. Masonry units are usually hollow and are made of concrete or clay. Vertical reinforcement bars are placed in the hollow cores, which are subsequently grouted with a cement-based grout to protect the reinforcement from corrosion. In reinforced masonry construction, vertical reinforcement mainly resists the effects of axial load and bending, whereas horizontal reinforcement resists shear. In confined masonry, the reinforcement is concentrated in vertical and horizontal confining elements whereas the masonry walls are usually free of reinforcement. Figure 3 illustrates the difference between reinforced and confined masonry construction (note that both examples use concrete block construction).

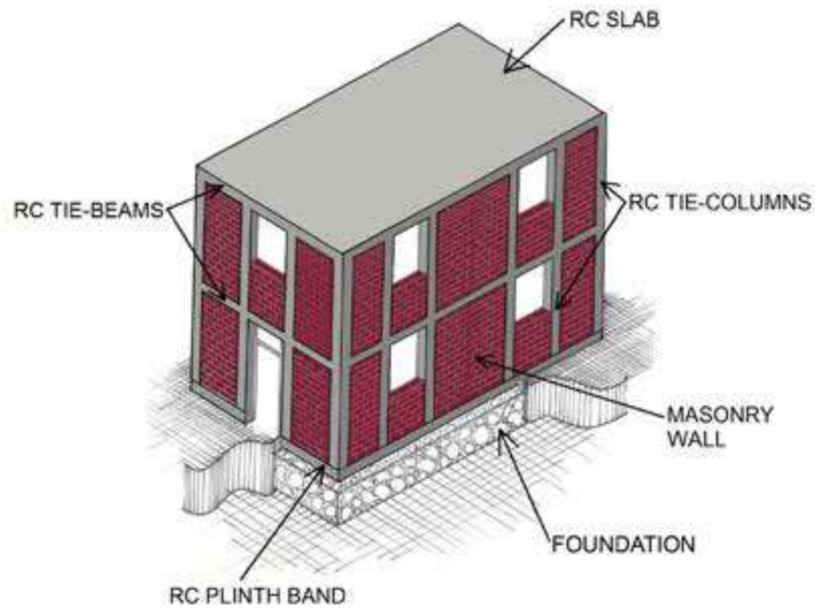

Figure 1. A typical confined masonry building1

Fig. toothing at the wall to tie column interface.

RESISTANCE OF CONFINED MASONRY TO EARTHQUAKE

A confined masonry building subjected to earthquake ground shaking can be modeled as a vertical truss. Masonry walls act as diagonal struts subjected to compression, while reinforced concrete confining members act in tension and/or compression, depending on the direction of lateral earthquake forces. This model is appropriate before the cracking in the walls takes place. Subsequently, the cracking is concentrated at the ground floor level and significant lateral deformations take place. Under severe earthquake ground shaking, the collapse of confined masonry buildings may take place due to soft storey effect similar to the one observed in RC frames with masonry infills. This behaviour was confirmed by experimental studies. It was reported after the 2003,Colima, Mexico earthquake, that a three-storey confined masonry apartment building in Colima experienced significant damage at the ground floor level. An effective way to avoid the fragile behaviour associated with the soft storey effect is to provide horizontal reinforcement in masonry walls in order to enhance their shear resistance. Research studies that focused on lateral load resistance of confined masonry walls identified the following failure modes characteristic of confined masonry walls:

• Shear failure mode, and
• Flexural failure mode.

In confined masonry structures, shear failure mode develops due to in-plane seismic loads (acting along in the plane of the wall), whereas flexural failure mode may develop either due to in-plane or out-of-plane loads (acting perpendicular to the wall plane). Shear failure mode is characterized by distributed diagonal cracking in the wall. These cracks propagate into the tie-columns at higher load levels, as shown in Figure 11. Initially, a masonry wall panel resists the effects of lateral earthquake loads by itself while the confining elements (tie-columns) do not play a significant role. However, once the cracking takes place, the wall pushes the tie-columns sideways. At that stage, vertical reinforcement in tie-columns becomes engaged in resisting tension and compression stresses. Damage in the tie-columns at the ultimate load level is concentrated at the top and the bottom of the panel. These locations, characterized by extensive crushing of concrete and yielding of steel reinforcement, are called plastic hinges. Note that the term *plastic hinge* has a different meaning in the context of confined masonry components than that referred to in relation to RC beams and columns, where these hinges form due to flexure and axial loads. In confined masonry construction, tie-beams and tie-columns resist axial loads. Shear failure can lead to severe damage in the masonry wall and the top and bottom of the tie-columns.

Experimental studies indicate that, in some cases, shear failure in confined masonry walls is preceded by the crushing of masonry in the middle portion of the wall. Similar damage patterns were also observed following the earthquakes that affected this type of construction in Chile. In some cases, out-of-plane failure of confined masonry walls took place without crushing in the middle portion of the wall; this confirms the importance of tie-columns in maintaining the vertical stability of masonry walls.

Flexural failure caused by in-plane lateral loads is characterized by horizontal cracking in the mortar bed joints on the tension side of the wall.

EATHQUAKE PERFORMANCE OF CONFINED MASONRY CONSTRUCTION

Confined masonry buildings have demonstrated satisfactory performance in past earthquakes. In general, buildings of this type do experience some damage in earthquakes, however when properly designed and constructed they are able to sustain earthquake effects without collapse. Latin America is certainly a region of the world where confined masonry construction is widely used and was tested in several significant earthquakes associated with the region's high seismic risk. According to Schultz (1994), low-rise confined masonry buildings have performed very well in past Latin American earthquakes. This applies to buildings regular in plan and elevation, which are lightly loaded and have rather large wall density. In such cases, confined masonry tends to be quite forgiving of minor design and construction flaws, as well as material deficiencies. Poor seismic performance has been noted only when gross construction errors, design flaws, or material deficiencies have been introduced in the building design and construction process. Poor performance is usually associated with tie-column omissions, discontinuous tie-beams, inadequate diaphragm connections, and inappropriate structural configuration. Seismic performance of confined masonry construction in Latin America and other parts of the world is discussed in this section.

The earliest reports describing the earthquake performance of confined masonry buildings date back to the 1939 earthquake (magnitude 7.8) in Chile. In Chillán, where a Modified Mercalli Intensity (MMI) of IX was reported, over 50% of all inspected confined masonry buildings sustained the earthquake without any damage, whereas around 60% of unreinforced masonry buildings either partially or entirely collapsed, resulting in a death toll of 30,000. Subsequently, the 1985 Llolleo earthquake (magnitude 7.8) with an epicentre in the central part of Chile, caused the collapse of 66,000 dwellings and damage to another 127,000 dwellings (the affected dwellings were mostly of adobe construction). Out of 84,000 housing units surveyed after the earthquake, around 13,500 units were of confined masonry construction. These buildings ranged from one-to- four storeys in height. Out of all inspected buildings, the most damage was inflicted to medium-rise buildings (3-to-5-storeys high); around 22% of these confined masonry buildings sustained severe or heavy damage. Low-rise buildings sustained very limited damage; only 2% of two-storey buildings were damaged, while none of the single-storey buildings were damaged. Overall, a large majority (76%) of the confined masonry buildings were undamaged (Moroni et al., 2004). Damage to confined masonry buildings was mainly due to the absence of tie-columns placed at wall intersections or around the openings; this again stresses the importance of tie-columns in ensuring the seismic resistance of confined masonry buildings. Damage to the confined masonry buildings in the 1985 Llolleo earthquake is illustrated in Figure 8

Figure 8. Damage to confined masonry buildings in the 1985 Llolleo, Chile earthquake1

Mexico is another country with a long record related to the application of confined masonry construction. Confined masonry is the most popular type of construction in Mexico, and it is widely used in the central part of the country. This type of construction is practiced both in the form of non-engineered construction (mainly found in rural areas and suburbs of urban centres) and engineered buildings e.g. industrial facilities and formal housing developments built under the supervision of qualified professionals.

Confined masonry buildings performed well in past Peruvian earthquakes shows a six-storey confined masonry building which was undamaged in the earthquake while the adjacent adobe building collapsed. However, confined masonry buildings with irregularities or poor detailing of reinforcement suffered extensive damage. Figure 9 b) shows a collapsed confined masonry building due to the soft storey effect.

CONCLUDING REMARKS Confined masonry buildings have performed well in several earthquakes worldwide. This construction practice is widely used in many countries and regions for the following reasons:

- It is based on traditional masonry construction practice;
- It does not require highly qualified labour (as is the case with RC frame construction);
- Confined masonry technology falls in between that of unreinforced masonry and RC frame construction, however due to its smaller member sizes and the large amount of reinforcement it is more cost-effective than concrete construction;
- It has a broad range of applications - it can be used for single-family houses as well as for medium-rise apartment buildings.

The following disadvantages are associated with confined masonry construction:

• Confined masonry construction is more expensive than unreinforced masonry construction and requires somewhat higher level of labour skills, however its earthquake performance is significantly better than unreinforced masonry construction;

• It is characterized by lower strength and ductility when compared to properly built ductile RC frame construction and may require larger wall area when compared to RC frame construction with masonry infills. Confined masonry construction has a great potential for saving lives and property in areas of high seismic risk in India. However, like any other construction practice, good earthquake performance is based on the following premises:

- Use of good quality materials,
- Good quality concrete and masonry construction, and
- Simple architectural design.

It is expected that this simple guideline featuring design and construction of confined masonry buildings will be useful to building professionals interested to learn more about this construction practice and engage in its design and construction.

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