Sustainability Aspects in Seismic Performance of Confined Masonry Structures: A Review

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Abstract

The brick masonry structures are mostly used in the construction industry for building up to two stories in the world. The unreinforced brick masonry structures performed not well during past earthquakes, which causes economical and human life losses. Confined brick masonry structures are proposed as reinforced brick masonry structures, which are now mostly used in developing countries. The seismic performance of the confined brick masonry structure is very important to withstand the structure while hit by the strong ground motion of earthquakes to reduce the economic losses as well as losses to human lives. The purpose of the work to construct the structures to avoid collapse of the structures during strong ground motion to reduce losses and use proper techniques, material to construct the structures with seismic load resistivity as well as economical. For the seismic performance of confined brick masonry structures, different research papers were studied to understand the effect of the stiffeners on brick masonry structures during strong ground motion. The papers studied including the analytical work on confined brick masonry structure, effects of past earthquakes on unreinforced and reinforced brick masonry structures, and Laboratory testing evaluation of the performance of confined/reinforced brick masonry structures while testing on shaking table by applying strong ground motion. The vertical and horizontal stiffeners used in brick masonry structures show improvement in the strength of the brick masonry structures and enhance the ductility of the brick masonry structures whiles testing on a shaking table with strong ground motion. From studies, it has been concluded that the reinforced concrete stiffeners improved the brick masonry structure's properties like strength, ductility, and avoid collapse of the structure during strong ground motion with peak accelerations. It has been also observed that during the past earthquake the reinforced/confined brick masonry structures performed well as compared to unreinforced brick masonry structures.

Keywords: *Confined brick masonry structures, seismic performance improvement, strength increase, ductility enhancing.*

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I. INTRODUCTION

The brick masonry structures especially unreinforced masonry structures are commonly used in many developing countries. The unreinforced brick masonry structures cause heavy damages in the past earthquake of the Hindu Kush earthquake 2015 of the magnitude of 7.5, which result in 280 fatalities and substantial damages to 109,123 buildings [Najif]. The failure of the unreinforced masonry structures is due to the seismic force resistance deficiencies, which cause heavy damages to the structures. For improving properties of unreinforced brick masonry structures, French Structural Engineer Paul Cottancin proposed the stiffeners provision method at the end of the 20th century (Edgell, 1985).

Confined masonry structures are widely used in the construction industry in the world, especially in Asia. Confined masonry structures are the basic structure of masonry with the provision of reinforced concrete columns and beam at a proper location like at corners, around openings, intersections, and places whether suitable and required to provide. The basic function of tie-columns in confined masonry structures is basically to improve the strength and ductility of the masonry structure or wall.

The confined masonry structures show better performance instead of masonry structures as observed in past earthquakes of Pakistan, Indonesia, Chili, and Haiti where the losses to property and life were mostly due to the collapse of masonry structures. The masonry structures were mostly used in past because of unawareness of enough knowledge. The provision of reinforcing stiffeners to brick masonry structures made the structures on the safe side to avoid heavy damages during the strong ground motions.

This paper is focusing on the improvement of seismic load resistance of the masonry structures by using different kinds of techniques and materials to enhance the stability of the structure as well as made structures economical. The work on literature review gives different techniques and materials which improve the seismic capacity of the structures. The techniques and materials selecting for confining of the structures must be enhanced the strength or seismic properties of the structures as well as make the structure economical by selecting cheap materials and easy method of construction of the structure.

II. CONCEPT OF CONFINED MASONRY (CM) STRUCTURES

Masonry construction is used for a longer time and still in many developing countries it is using because of the economic construction type. For proper construction of the confined masonry construction, it is necessary to understand the nature of confined masonry structures. To clear the concept about confined masonry structure we will know about what is confined masonry structure

and how it distributed or transfer the load. Masonry structures can be confined in different ways and materials like providing reinforced concrete tie-beams and tie-columns, timber material and can be reinforced by proving reinforcement in hollow bricks and poured with concrete. The most commonly used are tie beams and tie columns. For confining brick masonry structure horizontal and vertical reinforced concrete stiffeners can also be used which variate in size and reinforcement for different seismic zone and soil profile types [*Mehran*].

A. What is Confined Masonry

Confined brick masonry structures are some of the most commonly used structures in America, Europe, and Asia. In a confined brick masonry structure basically, the unreinforced brick masonry structure is confined by the provision of the horizontal and vertical reinforced concrete beams and columns, which is also known as tie-columns and bond beams. These columns and beams have enhanced the ductility of the structure and improve the lateral resistance of the structure to earthquake loadings and hold the brick masonry walls to avoid disintegration of the walls during earthquake lateral forces.

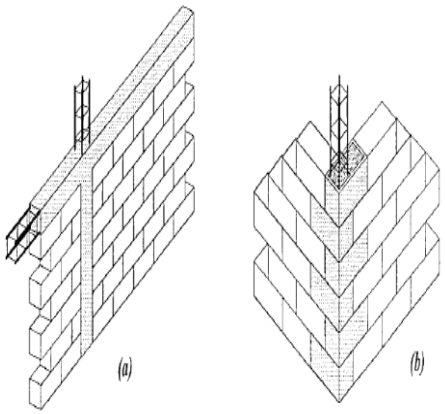

Figure 1. Confined Brick Masonry Walls [*Nasir*]

Confined masonry structure consists of basically the following structural and non-structural elements as given below.

a) Slab

In confined masonry structures, the floor slab and roof slab transferred vertical loads to the masonry walls to be transferred to the foundation properly. In a confined masonry structure, the slab behavior can be considered as a horizontal beam member in the structure.

b) Confining Beams and Columns

The confining elements like tie beams and tie columns provide to masonry walls are avoid disintegration of the masonry walls and withstand the structure vertically during the earthquake.

c) Masonry Walls

Masonry walls in confined brick masonry structures are usually transferred loads from roofs and slabs to the foundation through a plinth beam. Masonry walls behave as a vertical load carry member of the structure as well as resist lateral forces.

d) Plinth Beam or Plinth Band

Plinth beam or plinth band provide below the masonry and walls and above the foundation which transferred the vertical load from masonry walls to foundations.

e) Foundations

The Foundation of the confined brick masonry structure is basically the lowest structure member which transferred the load of the structure from plinth to ground.

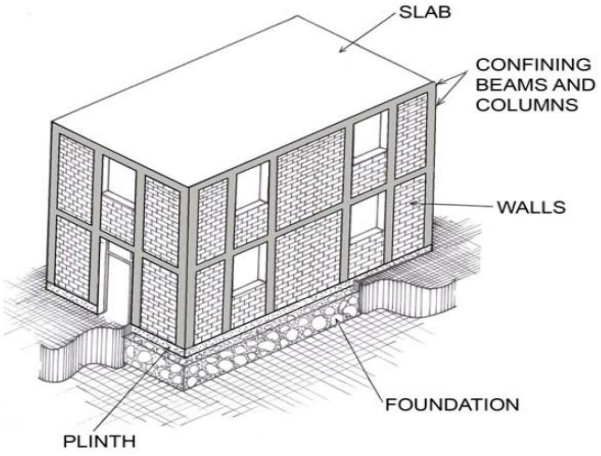

Figure 2. A typical Confined Masonry building of two-story [*Blondet,2005*]

B. How Confined Masonry Structure Different then Reinforced Masonry Structure

In confined brick masonry construction, the reinforcement is provided in confining elements like tie beams and tie columns while in reinforced masonry construction, the reinforcement is provided in brick masonry. For reinforced masonry construction the brick masonry used clay or concrete hollow inside for provision of the reinforcement as can see in figure 3 and figure 4. The confinement of the masonry structure is not only limited to the reinforced concrete stiffeners but also can be used steel, timber, and other similar kind of confining members, but here we are focusing on using reinforced concrete tie-beams and tie-columns as confining element of the masonry structure.

Figure 3. Confined Masonry Structure Construction in Indonesia [*Meisl*]

Figure 4. Reinforced Masonry Structure Construction in Canada [*Bill McEwen*]

C. How Confined Masonry Structure Different then RC Frame Structure

The confined masonry structure is totally different than the reinforced concrete Frame structure because of the construction procedure and transferring the vertical load to the foundation as well as in resisting the lateral seismic load. In confined masonry structure, the seismic lateral load resisting and transferring load to foundation from slab to beams and columns and beams to columns than from columns to foundation, while in confined masonry structure mainly the vertical load from slab transferred to brick masonry walls and from there to the foundation through plinth beam or band. The main differences between confined masonry structures and reinforced concrete frame structures are given in table-01.

Table 1. Comparison between Confined masonry and RC Frames Structures Construction

Types	Confined Masonry	RC-Frames
Load Carrying	In confined Masonry construction the vertical load is basically carrying by masonry walls as well as the lateral load is also carrying by masonry walls.	In RC Frames the vertical load is carrying by Beams and columns from slab to foundation as well as lateral load is also resisting by Frame members.
Foundation Construction	In confined masonry Strip footing and plinth beam or band constructed below the masonry walls	In RC Frames isolated footing, raft/mate, strip footing, pile footing and combined footings are constructing below columns.
Super Structure Construction	1. Construct masonry walls first. 2. Construct vertical tie columns. 3. Then construct tie beams on tie columns and masonry walls. 4. At the end construct the slab and roof.	1. First, construct the columns. 2. Then construct beams and slab/roof. 3. Then construct the masonry walls

III. SEISMIC PERFORMANCE OF CM STRUCTURES

A confined masonry structure is introduced basically for the improvement of a brick masonry structure to avoid disintegration of the masonry walls. The confined masonry structure should perform well during the strong ground motion. Seismic performance is observed in the different past earthquakes which show that confined masonry structure performs well as compared to the unreinforced or unconfined masonry structure.

A. Bam Earthquake

The earthquake occurred in December 2003, which hit the historical city Bam, Iran with a magnitude of M_w 6.7 causes too many losses to the economy and human lives. During the earthquake, most of the buildings collapse due to which approximately forty-five thousand people lost their lives. The brick masonry structures collapses fully while the newly constructed confined and reinforced brick masonry structures perform well and save human lives.

B. Peru Earthquake

The earthquake magnitude of 7.9 hit Pisco, Peru, which causes approximately 519 peoples to death and 1090 injuries. After the earthquake, it was found that confined masonry structures performed well as compared to unconfined masonry buildings. Some confined masonry structures collapse as well due to the soft story effect and also confined masonry building up to six stories performed well. The confined masonry structure which performed well in the earthquake up to six stories may be due to the proper confinement of the brick masonry structures. However, most of the confined masonry structures show better performance with little or no damages [*EERI, 2007*].

C. Central Java Earthquake

Central Java earthquake occurred in May 2006, which hit Java island, Indonesia with a magnitude of 6.3 killed 5,176 peoples and approximately 154,000 houses destroyed completely while 260,000 suffered from damages of different natures. However, the confined masonry structures performed well as compared to unreinforced and partially reinforced structures during the earthquake [*EERI, 2006*].

D. Chile Earthquake

The Chile earthquake occurred in 1985, which caused up to 66,000 buildings to collapse completely and damaged 127,000 houses. 13,500 houses out of 84,000 houses were confined masonry structures from 3 to 5 stories in height. However, the confined masonry building performed well generally as compared to unreinforced masonry buildings during the earthquakes.

E. Pakistan Earthquakes

Pakistan is located in the most active seismic region and hit by different disastrous earthquake-like the Quetta earthquake, Makran earthquake and Azad Kashmir earthquake as shown in table number 02.

Table 02. Major Disastrous Earthquakes in Pakistan

Date	Affected Area	M_w	Depth (km)
12-25-2015	Gilgit Baltistan, Khyber Pakhtunkhwa	6.3	212.5
9-24-2013	Awaran District, Balochistan	7.7	14.8
1-18-2011	Dalbandin, Balochistan	7.7	101
10-8-2005	Azad Kashmir, Balakot	7.6	15
2-27-1997	Balochistan	7	10
12-31-1983	Gilgit-Baltistan	7.2	214
11-28-1945	Makran Coast, Balochistan	8.1	25
5-31-1935	Ali Jaan, Balochistan	7.7	-

All of the earthquakes were disastrous but the Azad Kashmir, Balakot earthquake was the deadliest earthquake of Pakistan which killed more than 79,000 peoples and 65,308 were injured and other extensive damages occurred. At least 32,335 buildings were collapsed and a village in Muzaffarabad completely destroyed while in Uri 80 percent of the town was destroyed [*RPERA*]. These damages occurred due to the unawareness of the proper design guidelines and using of poor construction materials.

F. Comparison

From the seismic performance of the different structures during the past earthquake it has been observed that the places with a large number of unreinforced masonry structures suffered more than the places with a greater number of well-confined masonry structures. This means that the confined masonry structures perform well as compared to the unreinforced masonry structures. As can be seen that the earthquake magnitude of the Chile earthquake was more than the Indonesia earthquake but more losses to the structure have occurred in Indonesia as compared to Chile because of the construction of the well-confined structure in Chile as compared to Indonesia. These studies show that the confining elements like the provision of tie-beans and tie-columns hold the masonry walls in positions and enhanced the lateral resistance of the masonry walls to resist the seismic forces during the earthquake.

IV. SUSTAINABLE BUILDING

Sustainable building is the building that can improve and maintain the quality of life and harmonize within the environment in the region throughout the entire building life-cycle. In developing countries mostly construction is doing to construct economical buildings and the building can sustain itself during the earthquake loading. For sustainable building, research is in progress to use different sustainable techniques and materials to maintain the desired level of quality and performance of the building after seismic loading of earthquakes.

A. Sustainable Techniques

Sustainable techniques are the techniques used to construct the building to make the structures sustainable during earthquake loadings. Different researching techniques were used to enhance the masonry structure properties which contribute to the lateral load resisting capacity of the structures. The most commonly using the technique is the construction of vertical and horizontal columns, which sizes are proposed for different seismic zones and soil profile types to efficiently and economically construct the confined masonry structures [*Mehran, 2020*]. The effect of confining element checked on masonry structures and evaluate the properties of unreinforced and reinforced masonry structures, which shows that confining of masonry structure gives an easy approach to enhance the lateral load resisting properties of masonry structures [*Mehran, 2017*]. So, by using different techniques we can achieve seismically sustainable structures which can resist and withstand earthquake loadings. The most feasible and economical solution is providing the vertical and horizontal stiffeners at the required location of the structures which intern sustainable and economical solution.

B. Sustainable Materials

The seismically sustainable structures cannot be achieved without knowing and using efficient and good quality materials. For making structure seismically sustainable research scholar proposed a different kind of materials to be used to enhance the masonry and confined masonry structures lateral load resisting capacity. For this purpose, plaster with natural fibers used for mortar free interlocking wall, which show improving the lateral resisting of the wall by using a different kind of natural fibers like sisal, rice straw [*Furqan, 2018, 2020*]. Now a days different kinds of natural fibers, synthetic fibers, artificial and industrial fibers are using in concrete to enhance the concrete properties which in result enhancing seismic load resisting properties of structures. The very unique natural coconut fibers and their ropes used in concrete members like beams, columns and mortar free interlocking construction and testing under seismic and dynamic loadings which result very effective for improving the lateral load resisting capacity and can be very useful in the construction of seismic regions [*Majid, 2014, 2016, 2017*]. As these materials are used in concrete which shows a positive response of the structure while testing for the required properties. The plain cement plaster show increase in lateral resistance of the structure than the wall without plaster while the plaster of fiber mixed shows further enlacement in the lateral resistance of the walls. These materials were suggested to use to increase the seismic resistance of the structures and made the construction work economical as well by using local and natural materials for the improvement of structure sustainability. The addition of natural fibers in concrete and plaster enhances the lateral resistance of structure as well as reduces waste material pollution.

V. SUGGESTED IMPROVEMENTS IN CM STRUCTURES CONSIDERING SUSTAINABILITY ASPECTS

The confined masonry structures perform well as compared to unreinforced masonry structures as observed in the past earthquake that occurred in different countries. But it is observed that due to the unavailable of awareness in people of developing countries still people constructing unreinforced masonry structures. For improving the performance of confined masonry structures the following suggestions are given.

1. The proper footing of confined masonry should be constructed.
2. Vertical stiffeners or tie-columns should be provided at each corner of the building and rooms.
3. Tie-columns should be provided around the opening of the doors and windows.
4. Tie beams should be provided above openings of doors and windows.
5. The tie columns and tie beams should be connected and anchored properly.
6. Floor to floor should be properly constructed to avoid soft-story effects.
7. It would be better to limit confined brick masonry construction to the low-rise building of two to three stories.

By following the above steps and suggestions we can avoid the collapse of confined masonry structures and can reduce economic and human life losses. It has been learned from this literature review that we can be reinforced or confined the masonry structures by using different materials like timber, steel, reinforced concrete, and fiber reinforced concrete. The confining of the masonry structure basically enhances the seismic performance of masonry structures to reduce the losses during the earthquake. The reinforced concrete gives more sustainable structures as compared to other materials using for confining of the structures. The study gives us to properly understand of the concept of confined masonry construction and how it different then reinforced and frame structures.

VI. CONCLUSIONS

As in the past earthquake, it has been observed that unreinforced brick masonry structures cause a lot of losses to the economy and human lives due to totally collapsed of the structures while on other hand confined masonry structures and reinforced masonry perform well during the earthquake which reduces the losses to the economy and human lives. As comparing the earthquakes, it seems that the chile earthquake cause little damages to structures as compared to Java, Indonesia earthquake. This is because of the confining structures in Chile and well-designed construction houses while in Indonesia the damage occurred due to unreinforced construction. So, it has been concluded that,

1. The confining and reinforcing of the brick masonry structures enhanced the ductility of the masonry structures and hold the brick masonry wall in position and avoid disintegration of the masonry structures.
2. The confined masonry structures have more lateral resistance to seismic forces as compared to unreinforced masonry structures due to enhancing the lateral resistance

of the masonry structures by providing tie-columns and tie beams.

3. For better performance of the confined masonry structures, the tie-columns should be provided at all intersections of the masonry walls and provided around the openings of the doors and window and similar large openings.
4. Similarly, provide the tie beams at seven feet height of each story or above the opening of doors and windows level throughout the structure's walls.
5. It is concluded as well that the confined masonry shows better performance up to 2 and 3 stories of the buildings.

By following proper design guidelines of confined masonry structures and provide enough reinforcement according to the requirement of the structure we will be able to reduce the effects of the earthquake forces on structures and as a result will be able to reduce economic losses and save human lives.

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