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A Review On-Confined Masonry Construction

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Abstract

Masonry structures are popularly built in many parts of India so it is necessary to provide suitable guidelines and safety rules for proper construction of masonry buildings.Confined masonry (CM) structures is appearing as anaccepted building construction technique in many earthquake-prone countries including India. India falls under four earthquake zones namely, zone II, zone III, zone IV and zone V. CMconstruction type has been known to perform well in numerousmajorseismic events, even though it started as an informal construction. This paper is a review of various experimental studies done by various researchers in India and around the world who studied and analyzed on seismic performance of CM buildings. This paper also gives summarized construction guidelines of CM construction and also gives a comparison of CM and reinforced concrete (RC) frame construction. This study shows that CM building construction if standardized in India, under proper guidance of engineers and building codes can prove to be a better alternative to seismic resistant masonry construction.

Keywords: Confined masonry, earthquake, RC frame construction, seismic resistant.

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Introduction

Confined Masonry (CM) construction is a seismic resistant construction technique where the walls are confined with horizontal ties and vertical ties to ensure stability and safety during seismic loading [1]. Horizontal ties, also called tie-beams are comparable to beams in RC (reinforced concrete) frame construction but their function is different as in CM the load bearing structures are the walls. Vertical ties, also called tie columns are similar to slender columns in RC frame and have comparatively smaller cross-sectional area[2]. India falls under four earthquake zones namely, Zone-II, Zone-III, Zone-IV and Zone-V.The whole of northeastern India,parts of Jammu and Kashmir, parts of Ladakh, Himachal Pradesh, Uttarakhand, Rann of Kutch in Gujarat, some parts of North Bihar and Andaman & Nicobar Islands falls under Zone-V. Seismic zone distribution of India is shown in Figure 1. **(Annexure-1)**

In this construction technique the masonry walls are constructed prior to tie-beams or tie-columns. CM building after construction looks similar to RC frame construction but CM buildings the confines walls contribute load bearing but in the case of RC construction the column and beams are of bigger dimension and are the major load bearing structures [3,4].

Structural elements of CM buildingsare shown in Figure 1. [2,3,5]-

Foundation

It is the structure usually built underground which is used fortransmissionof loads from the building structure to the soil.

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RC Plinth Band

The structural elements built from ground level(GL) to floor level are consider as plinth. These structure helps in transferring loads from wall to the foundation and also lessens the risk of settlement.

Confined Masonry Walls

The masonry walls help in transferring gravitational and lateral loads from slabs (floors and roofs) to the foundation.These masonry walls are confined in all four directions by horizontal and vertical ties ensuring safety and prevention from collapse during earthquakes.

Roof Slabs and Floor

They are similar to floor slabs and roofs in RC frame construction. They transfer lateral and gravitational loads to the walls.

Confining Elements

They are the horizontal and vertical ties infilled with rebars. They are resistant to gravitational loads and protects the walls from collapse during major earthquakes.

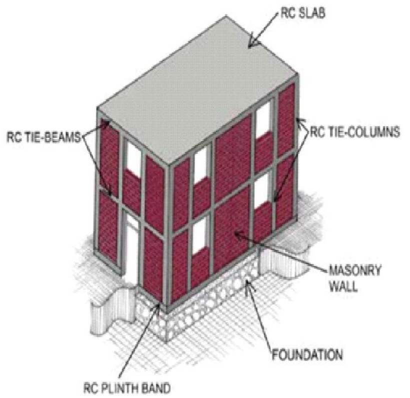

Figure 2: Typical CM building showing its structural elements (Brzev,2007)[5].

CONSTRUCTION GUIDELINES

The main approach for construction CM building is that the rebars for vertical ties should be placed first at the plinth level fixed to the RC plinth beam and the masonry walls are to be constructed between the vertical rebars. Vertical ties are then casted on the formwork confining the walls [3,4]. Then, the horizontal ties are casted together with floor slab (if required) after the completion of masonry wall construction to the desired height(maximum of 3m) [3].

There are certain principles that needs to be followed while constructing CM buildings such as [3]-

a. The maximum ratio of horizontal ties and vertical ties is 1:3 i.e., the length of the building should not exceed three times the width, each façade should have atleast one shear wall (confined walls with no openings), regular shapes are preferred however complex shapes can be created by building separate blocks providing a seismic gap of 40-60 cm. The walls ought to be continuous along the vertical and there must not be any cantilever formation.
b. There should be enough free space distance on every side of the building. CM buildings should not be built on embankments or near to a cliff or flood prone areas.
c. Continuous strip footings are preferred and the plinth band should be of width 20cm and depth of 15cm.
d. The masonry wall units (brick, concrete block, etc.) should be stacked in Flemish bond formation and the wall should be built in 1.2m height per day and a seismic band, if required, should be added. Also, there should be a spacing (toothing) of 3cm-5cm between the masonry wall and reinforcement of vertical ties at both ends.
e. Casting of vertical ties should be done within 90 minutes of concrete mixing. Concrete should be poured in 30cm - 60cm layer and compacted. Formwork should be supported using wood planks to ensure stability and spacers of 3mm thickness should be provided
f. Seismic reinforcement should be provided on each side of every opening i.e., doors, windows, etc. Forconfining elements ribbed steelrebars are preferred.
g. Primary rebars should be inserted along the width of the building and secondary rebars along the length on top of primary rebars. Insert hook slab rebars into the horizontal tie rebars to ensure proper connection. The formwork of the slab should be wetted with water prior to concrete pouring.
h. Light roofing with independent verandah from the main roof is preferred to avoid tear off due to strong wind.

MATERIALS USED FOR CONSTRUCTION

Building materials used for construction of CM buildings are similar to that of RC frame construction i.e., cement sand, coarse aggregate, bricks (or masonry blocks) and steel for reinforcement.

Comparision of CM And RC Frame Construction

Table-1: Comparision of CM and RC frame Constructon[5,6,10]

Parameter	CM construction	RC frame construction
Gravity and lateral load resisting system	Masonry walls are the key elements to avert gravity and lateral loads	RC frames withstand lateral load and gravity and lateral loads with greater beams, columns, and their connections. Masonry infills are not load-bearing walls.
Foundation construction	Strip footing below the wall and the RC plinth band	Isolated footing below each column
Superstructure construction sequence	1.First masonry walls are constructed. 2.Parallel, tie-columns are cast in place. 3.Finally, tie-beams are constructed on top of the walls, in parallel to floor/roof slab construction.	1.First construction of frame is carried out. 2.Masonry walls are constructed at a later stage and are not bonded to the frame members; these are non-structural, that is non-load bearing walls.

Low-rise CM structure performs better in-plane and out-of-plane resistance compared to under reinforced masonry and infilled RC frame structures under any earthquake event.[18]

Experimental Findings of Different Researchers

A review of the work carried out by different researchers in the field of confined masonry construction are discussed below.

Kushal J. Desai et.al.[7] performed a case study on a confined masonry wall with three openings (two doors and one window) on a building of IIT, Gandhinagar.

He concluded that CM executeswell under earthquake load in comparision with conventional masonry construction.

Sorina Constantinescu [8]studied on the ductile behaviour, nonlinear behaviour of a CM building in earthquake prone areas (Bucharest, Romania). The study was performed on a 3D model and the nonlinear behaviour of the building was studied on two perpendicular lateral directions i.e., X and Y directions.

It was concluded that confined masonry building shows a firm behaviour and hysteresis curve was not shown. When stresses in the masonry wall exceeds design strength, the masonry wall fractures but the building does not breakdown prior to plastic hinge formation and structure becomes mechanism.

S. Brzev [9] reviewed on design and construction guiding principle for engineered and low heightnonengineered confined masonry buildings. Design codes for confined masonry wall panels for in-plane and out-of-plane seismic effects are also well examined. He concluded that the review outlines development and recommendations of design and construction guidelines for confined masonry buildings in regions prone to seismic hazard.

Ajay Chourasia& S.K. Bhattacharyya [10] discussed on masonry construction in Indian scenario and studied on the performance of CM buildings on past earthquakes and its behaviour under lateral cyclic loading. They also compared the codal provision of selected countries and the lack of codal provision and experimental data of CM in India.

It was concluded that CM is a promising technology the performs better under seismic loading and exhibits no significant damage. Also, the performance of CM buildings in India in comparison with unreinforced masonry (URM) and reinforced masonry (RM) in strength showed about 3.42 & 2.3 times improvement respectively.

ArlePratibha. R et.al.[11] performed a seismic analysis of CM building and RCC (Reinforced concrete construction) building using ETABS software and manual calculation. The study also gives a comparison of RC frame construction and CM construction on different parameters like load resisting system, foundation construction, etc.

It was concluded that for seismic region CM buildings give a better alternative for lowcost earthquake resistant building construction.

VaibhavSinghal et.al. [12] performed an experimental assessment of out-of-plane reaction of CM walls with openings when impairedby in-plane forces.

It has been noticed that CM walls maintained structural integrity even after severe damage and the out-of-plane displacements were lesser compared to RC frame structures. Also, the horizontalpotency and energy dissipation of confined wall with fissures were 40% more higher than that of infill wall with lintel beam over the opening.

The experimental result shows that all round confinement of masonry walls with RC elements increases both in-plane and out-of-plane reaction of masonry walls.

Asfandyar Ahmed et.al.[13]analysed the seismic functioning of CM brick buildings in earthquake prone areas of Pakistan and other similar regions of the world.

The results from this experimental study concluded that CBM building issturdy against seismic loads because of the confining elements and is efficient in enhanching the seismic performance.

Ajay Chourasia et.al.[14] performed an experimental study on seismic strengthening technique of confined masonry building using Plastic Cement Bag Mesh (PCBM). Strengthened confined masonry building (CM_ST) come out to be seismic resistant building for masonry buildings of low height to medium height.

It was determinedas of the finding that CM_ST building showedmaximum lateral load carrying capacity by exceeding 24.18% as compared to CM buildings. And CM_ST building has a ductility of 6.21 whereas CM building has 5.75. The used of PCBM resulted in improvement of ductility of CM_ST but it was also stated that PCBM could have some draw backsregarding durability, creep and fatigue.

D. Tripathy& V. Singhal[15] performed a non-linear parametric analysis using strut-and-tie analysis to comprehend the performance of masonry strut and proposed a detailed method for the designand construction of the strut-and-tie model for CM walls.

It was concluded that the suggestedmethod offered effective calculations for the in-plane shear capacity of CM walls and can be of additional used for the design and analysis of CM buildings.

Ajay Chourasia et.al.[16]analyzed the earthquake resistance of a CM building with light weight cellular (LWC) panels, under displacement controlled quasi-static reversed cyclic lateral loading.

Based on the experimental results it was concluded that CM building exhibited good performance withnosubstantialdamage, and so the system can be accepted for constructing low height to medium height buildings, providing speed, sustainability and economy.

VaibhavSinghal&Durgesh C. Rai [17] performed a study that was focusing on the assessment of the out-of-plane reaction of CM walls with toothed joints when impairedcaused by in-plane forces.

It was found that CM walls sustainedphysicalstate and out-of-plane firmness even when harshlyimpaired. The CM walls including or excludingtoothingimproved the interfaceabout masonry walls and the confining elements of reinforced concrete and were capable ofdecelerating the collapse by restraining out-of-plane bends even at 1.75% in-plane drift cycle.

Discussion Of Results On The Findings

It was observed from the analysis thatthe calculated moment of resistance of the wall under compression (on masonry) and tension (on steel) to be 2983.4 kNm and that the value of the moment of resistance can be manipulated by changing the area of steel at various positions and found to be higher than actual moment carried by the particular wall as per seismic and reinforced distribution calculation.[7]

It was observed that plastic hinges developed at the ends of tie-beams and at the bottoms of tie columns. In nonlinear analysis on X-direction, almost all hinges on marginal beams reach a stage where loads are redistributed but, collapse stage was not reached. Plastic hinges were found to arise more in the tie-beams than at the bottom of tie-columns. And, in nonlinear analysis on Y-direction, collapse stage is reached and the structure becomes a mechanism.[8]

Design guidelines for engineered and non-engineered confined masonry buildings were elaborately discussed. Design codes for CM wall panels for in-plane and out-of-plane seismic effects are also well analyzed and examined.[9]

Overall observation showed improvements in seismic performance of CM building over unreinforced masonry and RM, when full scale test on one room size masonry model of 3.01mx3.01m in plane and 3.0m high has been conducted under quasi-static cyclic lateral displacements.[10]

In this study, results are obtained from software calculations giving analytical results and also, from manual calculation for each storey of CM and RCC building which was analyzed.Displacement in CM building is lesser in comparison to RCC building in both static and response spectrum analysis. Storey drift of a CM building is smaller than RCC building due confinement of walls of building.[11]

It was observed from the study that CM specimens did not undergomajor deflection till the drift cycle of 1.75%.

Vertical splitting cracks in close proximity to the wall-to-tie-column interface were detected in CM wall after 1.75% in plane drift.

The ratio of load-carrying capacity of walls with opening and the conforming solid masonry walls was 0.62 to 0.99.

Wall with infilled masonry exhibited continuous increase in out-of-plane bends with in-plane destructionowing tofeebleconnection between masonry and confining frame and was on the point of collapse after 1.75% drift cycle still the CM wallsustained the out-of-plane stability even after amassinghuge in-plane destruction.[12]

From the experimental results it was observed that at a story drift of 0.093%, the lower left corner of pier 2 start exhibiting diagonal hair line crakes and extended till the lintel beam. And, hair line cracks start exhibiting at the center of pier 2 over the silllevel at a story drift of 0.16% which extended to the lintel beam. The diagonal shear cracks spreads and spread out to the lintel beam in pier 2 at a story drift of 0.34%. Both of the tie columns of the high strength wall fractured at the mid point due to flexure stresses at story drift of 0.73%.[13]

The results found from the experimental study were-

CM building in-plane wall go throughinitial flexural plane hairline crack observed in close proximity to the toe region of 7 mm displacement, while CM_ST undergo its initial flexural hairline crack of 12 mm displacement.

Lateral load resistance growth was observed in CM_STof 24.18% paralled with CM building.

The primaryrigidityacquired was 63.33 kN/mmin the case CM_ST building,whereasprimary rigidity was 56.74 kN/mm in case of CM.

For CM_ST building, highestshowedto 2.48% at the limit state of safety, while for CM building was 1.80%.

Total dissipated energy of 7804 kN-mm was displayed by CM_ST, i.e., 83.62% greatercompared to CM building.[14]

It was observed that the in-plane shear competence of the wall with aspect ratio 1.0 raised with the rise in wideness of wall as of 120 mm to 240 mm. Also, the in-plane shear strength raised marginally (under 30%) whendeviation of 150 to 200 mm and 250 to 300 mmin the height of tie-column, respectively. Thus, with therise in masonry compression strength and wall wideness, the in-plane shear capacity also rises but, hardlyhave an effect on the shear capacity of CM walls is not affected bythe strength of concrete in the tie-column and size of tie-elements and to stabilize the consequence of these parameters, a relative stiffness factor was set up.[15]

The initialcrosswise hairline crack was observed at in-plane walls at 7 mm. At displacement cycle of 65mm, substantialspreading of cracks, compressing at junctions of panels, parting at masonry-tie-column interface and concrete compressing in confining elements were observed. The highesthorizontal load of 133.6 kN at horizontal displacement of 30.8mm was achieved by CM building. The CM building exhibited main damage at 65mm displacement.

The CM building attainedtill the highest drift of 2.17%, before reaching collapse failure.[16]

The specimen using infill masonry exhibitedparting of the masonry wall from RC ties and vertical ties even at an in-plane drift level of 0.5% whereas, the CM wall did not undergo any partitionup toa drift cycle of 1.75%.

The CM wall specimens were efficient in decreasing out-of-plane bendseven beyond an in-plane drift (damage) of 1.75%.

The CM specimen exhibited a slimrise in the in-plane endurance by 7 to 15% in comparison with infill masonry panel.[17]

Conclusion

From the review study, it can be concluded that confined masonry buildings, if constructed under appropriate guidance of engineers and building codes, performs well and gives satisfactory results in terms of safety under high seismic load.

Since majority of the states of India falls under major earthquake zones, seismic resistant structures are very much in need. Also, the whole of northeastern part of India falls under Zone V which indicates that building structures are vulnerable to seismic loads. Currently, northeastern India is quite under developed compared to mainland India and high rise structures are not very common in the area. However, as urbanization is taking place at a rapid pace, construction of high rise buildings will eventually be very common in near future. This demands the need for seismic resistant measures. Meanwhile, CM construction being a seismic resistant construction may prove to a better option towards achieving earthquake resistant structures. In addition to seismic resistant, construction of CM building is economical as compared to RC buildings. The materials required in the construction of CM buildings are the same as those of conventional buildings which suggest that the availability of the materials will not be an issue. Hence, with proper guidelines and codes, CM construction technique will prove to be a better alternative for seismic resistant construction. Formulation of a specific IS code for Confined Masonry Construction will be of great help for seismic resistant construction.

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Annexure-1

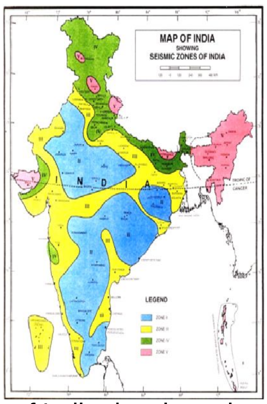

Figure 1: Map of India showing seismic zones of India (IS 1893-1 : 2016) [6]