Confined Masonry: An Alternative to Low Rise RC Frame Construction

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Abstract: **Load bearing masonry construction was most widely used form of construction for large no of buildings from 17th Century to the mid19th century. It is very rarely used for large buildings, but smaller residential-scale structures are still being built. The load bearing masonry if confined with tie beam and tie columns may greatly enhance the earthquake resistance capacity of the structures. Construction of the buildings with confined masonry load bearing walls has been in practice in many parts of the world in high earthquake risk zones. However this typology of the building construction is very rare in India and rarely practiced in Govt approved construction projects. Military Engineer Service is one of the largest construction organizations in the country and is engaged in planning, designing and execution of specialized projects in all kind of earthquake zones throughout the length and breadth of the country. The construction works in defense ranges from simple structures to the very complex ones, suitable to the varying needs of Army, Air Force, Navy and DRDO. In recent times the planners and designers in MES have given a go by to the traditional load bearing structures even for single storey constructions located even in least earthquake prone areas. Confined masonry offers an alternative to both unreinforced masonry and RC frame construction for applications in earthquake prone areas of the country. A transition from RC framed construction to confined masonry construction in most cases leads to savings in concrete and steel and with less intricate reinforcement detailing. Improved seismic performance will be achieved by use of reduced amount of materials and labour typically associated with RC framed construction. This means "less for more". IIT Gandhinagar has taken a lead in this regard by constructing buildings up to four storyes in its new campus in Gandhinagar, Gujarat.**

Keywords: **Confined Masonry, Wall Density, Confining Members, Tie Beams, Tie Columns.**

1. INTRODUCTION

1. Poor performance of unreinforced masonry and poorly-built reinforced concrete (RC) frame construction in past earthquakes caused high human and economic losses and prompted a need for alternative building technologies with enhanced seismic performance. One such technology is confined masonry, which has emerged as a building system that offers an alternative to both unreinforced masonry and reinforced concrete (RC) frame construction. Confined masonry construction has evolved though an informal process based on its satisfactory performance in past earthquakes.

2. In India the vulnerability of the constructions in the past earthquakes has been amply demonstrated by the damaging earthquakes such as the one in Bhuj in 2001 and Jammu and Kashmir in 2005. The damages included not only to the non-engineered constructions carried out by the common man, but also many "engineered" buildings. These experiences have led to issue of several instructions/ guidelines on the building typology to be followed in Military Engineer Services (MES). As sequel to this R C Framed construction has become the choice of planners and designers in MES even for simplest of the single storey buildings. The performance of RC frame construction lies in detailing of reinforcement and its faithful execution by skilled labour in the backdrop of exponential growth of the construction sector in India. The confined masonry construction technology can be an alternative to the complex RC frame construction for at least 2-3 storey buildings having better response to the earthquakes in earthquake prone areas of zone II to zone IV.

2. CONFINED MASONRY AND RC FRAME CONSTRUCTIONS: A COMPARISION

3. Confined masonry has features of both unreinforced masonry and RC frame construction. Confined masonry construction consists of masonry walls (made of clay/ flyash bricks or concrete block units) and horizontal and vertical RC *confining members* built on all four sides of a masonry wall panel. Vertical members are called the "*tie columns"* or *"vertical ties"* and horizontal elements are called *"tie beams"* or *"horizontal ties"*.

The appearance of a finished masonry construction and RC frame construction with masonry infills may look alike to a lay person; however these two construction systems are substantially different. The differences are summarized in Table-1 and are illustrated in the Figure-1.

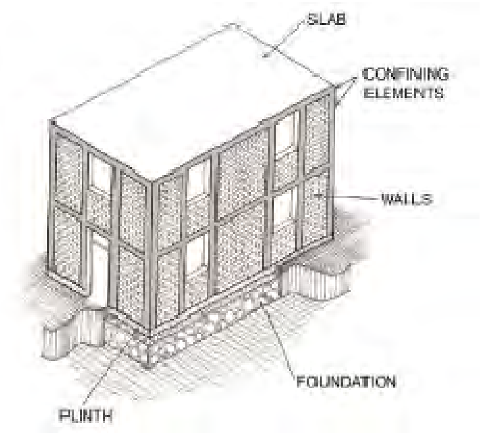


Fig. 1. A typical confined masonry building

TABLE 1: A comparison between the confined masonry and RC frame construction

	Confined masonry construction	RC frame construction
Gravity and lateral load resisting system	Masonry walls are the main load bearing elements and are expected to resist both gravity and lateral loads. Confining elements (horizontal and vertical ties) are significantly smaller in size than RC beams and columns	RC frames resist both gravity and lateral loads through their relatively large beams, columns and their connections. Masonry infills are not load bearing walls.
Foundation Construction	Strip footing beneath the wall and the RC plinth band	Isolated footing beneath each column
Superstructure construction sequence	1. Masonry walls are constructed first 2. Vertical ties are cast in place 3. Finally, the horizontal ties are casted on top of the walls, simultaneously with the floor/roof slab	1. The frame is constructed first 2. Masonry walls are constructed at a later stage and are not bonded to the frame members, these walls are non-structural, i.e. non-load bearing walls

4. In confined masonry construction the confining elements are not designed to act as moment resisting frame; as a result detailing of reinforcement is simple. In general confining elements have smaller cross sectional dimensions than the corresponding beam and columns in a RC frame building.

3. WORLDWIDE APPLICATION

5. Confined masonry construction has evolved through an informal process based on its satisfactory performance in the past earthquakes. The first reported use of confined masonry construction was in the reconstruction of buildings destroyed by the 1908 Messina, Italy earthquake (M 7.2), which killed over 70, 000 people. The practice of confined masonry construction started in Chile in the 1930’s after the 1928 Talca earthquake (Magnitude 8.0) that affected the significant number of unreinforced masonry buildings. Subsequently, the 1939 earthquake (Magnitude 7.8) that struck the mid-southern region of Chile revealed very good performance of confined masonry buildings. Over the last 30 Years, confined masonry construction has been practiced in Mediterranean Europe (Italy, Slovenia, and Serbia), Latin America (Mexico, Chile, Peru, Argentina, and other countries), the Middle East (Iran), south Asia (Indonesia), and the Far East (China). It is important to note that confined masonry construction practice exists in countries and regions of extremely high seismic risk. Several examples of confined masonry construction around the world, from Argentina, Chile, Iran, Peru, Serbia and Slovenia, are featured in the World Housing Encyclopedia (EERI/IAEE 2000).

6. Confined masonry has been used for construction of single storey family housing and also two to three storey medium rise apartment buildings. The limit of four storey building height coincides with most construction code’s height restrictions for the buildings without elevators. It is a common practice that low rise confined masonry buildings (upto two storey) are non-engineered, whereas engineers and architects are involved in the design of taller apartment buildings.

7. In one of a major shift in the building construction practices in India, the hostels for the students and residential apartments for the faculty and staff of the IIT Gandhinagar have been constructed with the confined masonry with FALG brick units. The hostels have been constructed with six blocks of four storey (Plinth area 36000 Sqm) and 270 no. (30 blocks of nine units each) of residential apartment buildings with three storey (Plinth area 49000 sqm).

4. EARTHQUAKE RESISTANCE BY CONFINED MASONRY BUILDINGS

8. A confined masonry building subjected to earthquake ground shaking can be modelled as a vertical truss as shown in Figure-2 (left). Masonry walls act as diagonal struts subjected to compression, while reinforced concrete confining members act in tension and/or in compression, depending on the direction of the lateral forces. This model is appropriate before the cracking in the walls take place. Subsequently, the cracking is concentrated at the ground floor level and significant lateral deformation take place. Under severe earthquake ground shaking, the collapse of confined masonry building may take place due to soft storey effect similar to the one observed in RC frames with masonry infills, as shown in Figure-2 (right).

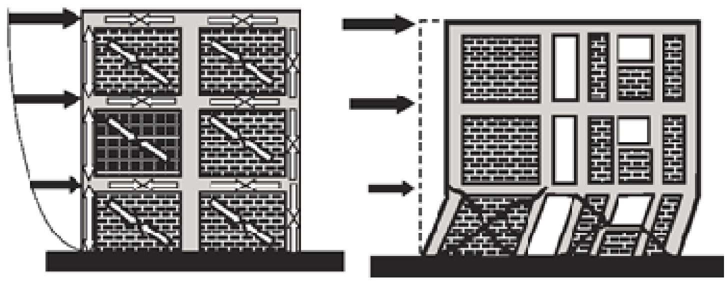


Fig. 2. Confined masonry building: vertical truss model (left) and collapse at the ground floor level (right)

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,

Note that, 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 2. 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* (see Figure-3). 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.

Shear

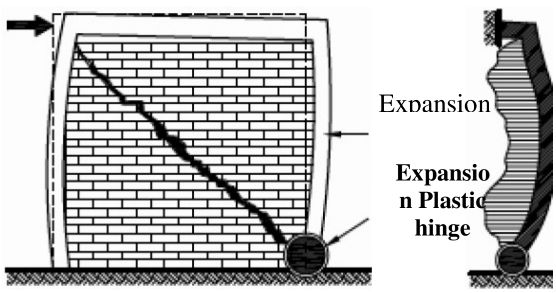
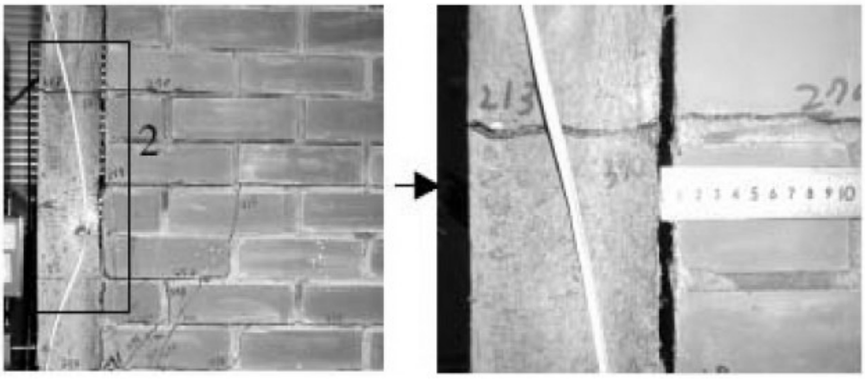


Fig. 3. Plastic hinge developed in a confined masonry wall

10. *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, as shown in Figure-4. Separation of tie-columns from the wall was observed in some cases (when toothed wall-to-column connection was absent). Extensive horizontal cracking, which usually takes place in tie-columns, as well as shear cracking can be observed.



View-1 **View-2**

Fig. 4. Flexural failure of confined masonry walls

Experimental studies have shown that, irrespective of the failure mechanism, tie-columns resist the major portion of gravity load when masonry walls suffer severe damage (this is due to their high axial stiffness and load resistance). The failure of a tie- column usually takes place when cracks propagate from the masonry wall into the tie-column and shear it off. Subsequently, the vertical stability of the entire wall is compromised. Experimental studies have shown that vertical strains in the confined masonry walls decrease at an increased damage level, thereby indicating that a major portion of the gravity load is resisted by tie-columns. This finding confirms the notion that tie- columns have a critical role in resisting the gravity load in damaged confined masonry buildings and ensuring their vertical stability.

5. KEY FACTORS INFLUENCING SEISMIC RESISTANCE OF CONFINED MASONRY STRUCTURES

5.1 Wall Density

Wall density is believed to be one of the key parameters influencing the seismic performance of confined masonry buildings. It can be determined as the transverse area of walls in each principal direction divided by the total floor area of the building.

5.2 Masonry Units and Mortar

The tests have shown that the lateral loads resistance of confined masonry walls strongly depends on the strength of the masonry units and the mortar used. The walls built using the low strength of bricks or hollow ungrouted block units had the lowest strength while the ones built using grouted or solid units had the largest strength. Also weaker the mortar lower will be the masonry strength (due to the unit-mortar interaction, the masonry strength is always lower than the unit strength). Tests have also shown that there is no significant difference in strength between unreinforced and confined masonry wall specimens with the same geometry and material properties.

5.3 Tie-Columns

Tie-columns significantly influence the ductility and stability of cracked confined masonry walls. Note that the effect of tie-columns on increasing lateral resistance of confined masonry structures has only recently been recognized. The provision of closely spaced transverse reinforcement (ties) at the top and bottom ends of tie-columns results in improved wall stability and ductility in the post-cracking stage.

5.4 Horizontal Wall Reinforcement

In many countries where confined masonry construction is practiced, reinforcement is usually not provided in masonry walls. However, in four-to-five storey construction in Peru there is a tendency to provide horizontal joint reinforcement in the form of one or two wires laid in the mortar bed joints. The Mexican Code NTC-M 2004 prescribes that the horizontal reinforcement, when provided, be placed continuously along the wall length. Horizontal rebars should be anchored into the tie-columns; the anchorage should be provided with 90° hooks at the far end of the tie-column.

5.5 Openings

An experimental research study showed that, when the opening area is less than approximately 10% of the total wall area, the wall lateral load resistance is not significantly reduced as compared to a solid wall (i.e. wall without openings). The walls with larger openings develop diagonal cracks (same as solid walls), except that the cracks are formed in the piers between the openings; thus, diagonal struts form in the piers, as shown in Figure-5. The study recommends estimating the lateral strength of walls with window openings based on the net transverse wall area (equal to the wall thickness times the wall length reduced by the sum of window lengths). Note that, in this study, the vertical reinforcement bars were provided around the openings. Most building codes prescribe the maximum permitted opening size beyond which the tie-columns need to be provided.

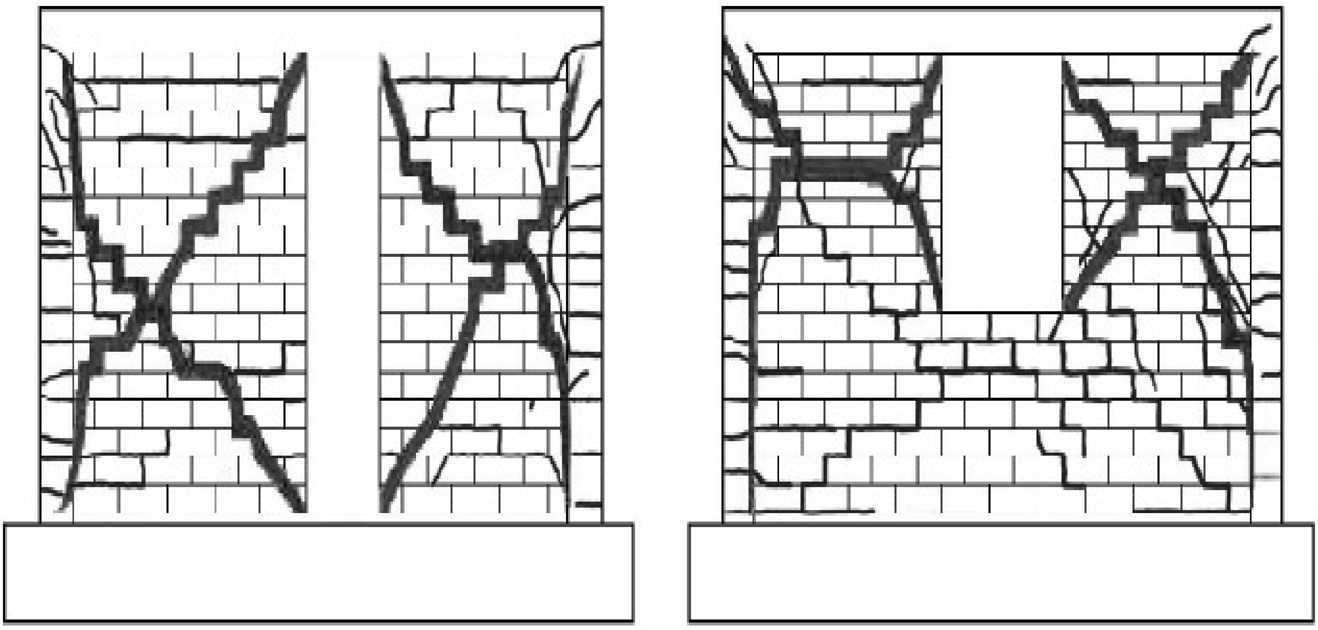


Fig. 5. Failure mode in the confined masonry walls with openings

6. EARTHQUAKE PERFORMANCE OF CONFINED MASONRY CONSTRUCTION

12. Confined masonry buildings construction is extensively used in Latin America, Mexico, Iran, China, Columbia, El Salvador and Peru. These countries have experienced earthquakes of magnitudes of 7.5 to 8.0 on Richter scale. Sufficient data are available to state that the confined masonry buildings in these countries 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. 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. The Figure-6 testifies these claims for low rise buildings.

(a)

(b)

(c)

(d)

Fig. 6. Performance of confined masonry construction in the 2001 El Salvador earthquake: a confined masonry buildings in town of Santa Cruz Analquito still standing, while the surrounding adobe construction was destroyed; b) a confined masonry school building survived the earthquake without damage, while the nearby adobe buildings collapsed; c) shear cracking in the walls of a confined masonry building; d) a courthouse in Santiago de Maria - an example of soft story construction (confined masonry construction at the ground floor level)

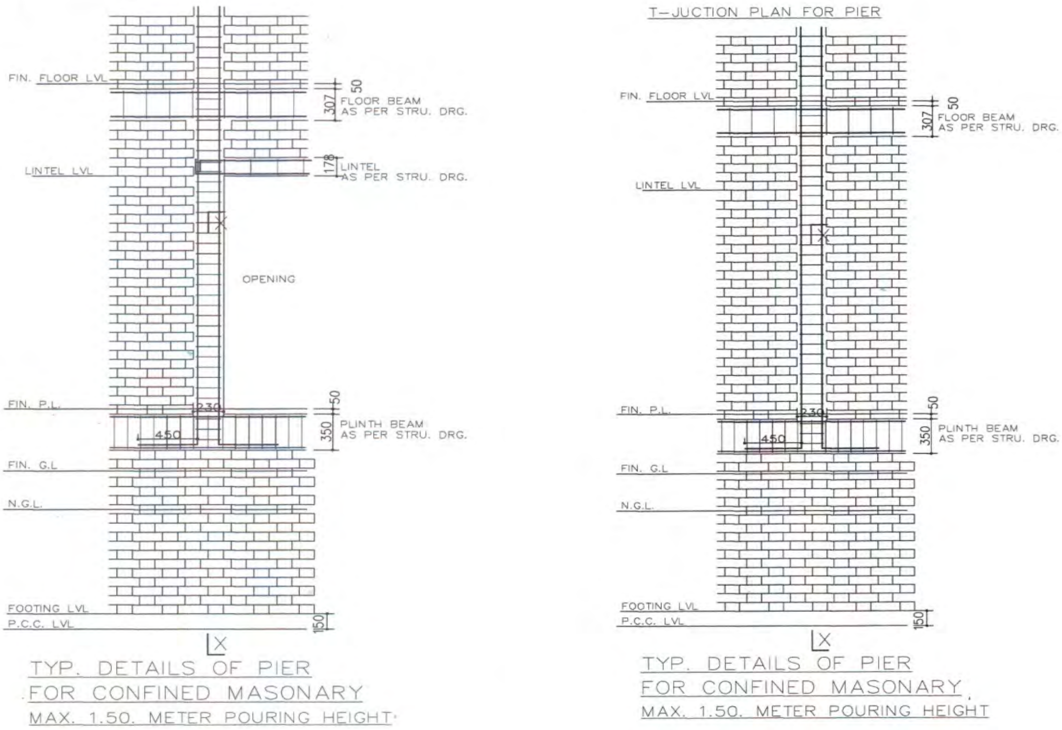


Fig.7. Typical details of pier for three storey residential building

7. A CAMPUS ON THE BANKS OF SABARMATI WITH CONFINED MASONRY

13. Having started in 2008 at a transit campus in Ahmedabad, IIT Gandhinagar has acquired 400 acres land in Sep 2012 to develop it's new campus on eastern bank of Sabarmati river near Palaj village in Gandhinagar district. The master plan envisions a campus on the river Sabarmati, determined in a large measure by the river bank location and the extensive features of ravines. It is planned as a green campus. The phase I of the development include hostels for 1200 students and 270 residential units and academic complex. The work had started in Sep 2013. The construction of hostel buildings in four storey and residential blocks are in three storeys with confined masonry construction with fly ash bricks. The total plinth area under construction with this typology is approximately 85000 Sqm. By far now this is the first of it's kind in India to have confined masonry construction on such a scale in the earthquake zone III of the country.

14. The three storey residential buildings and four storey hostel buildings have been designed based on the EERI literature and Mexican codes as no Indian Standard is available on confined masonry constructions. All the masonry below plinth

level has been taken with burnt clay bricks with minimum strength of 5 MPa and maximum water absorption of 15%. All the masonry above plinth level is fly ash (FALG) bricks confirming with minimum strength of 9 MPa and maximum water absorption of 20%. Typical details of the piers for confined masonry adopted in the construction are shown in Figures-7. Typical cross sections of the wall footings adopted are shown in Figure-8.

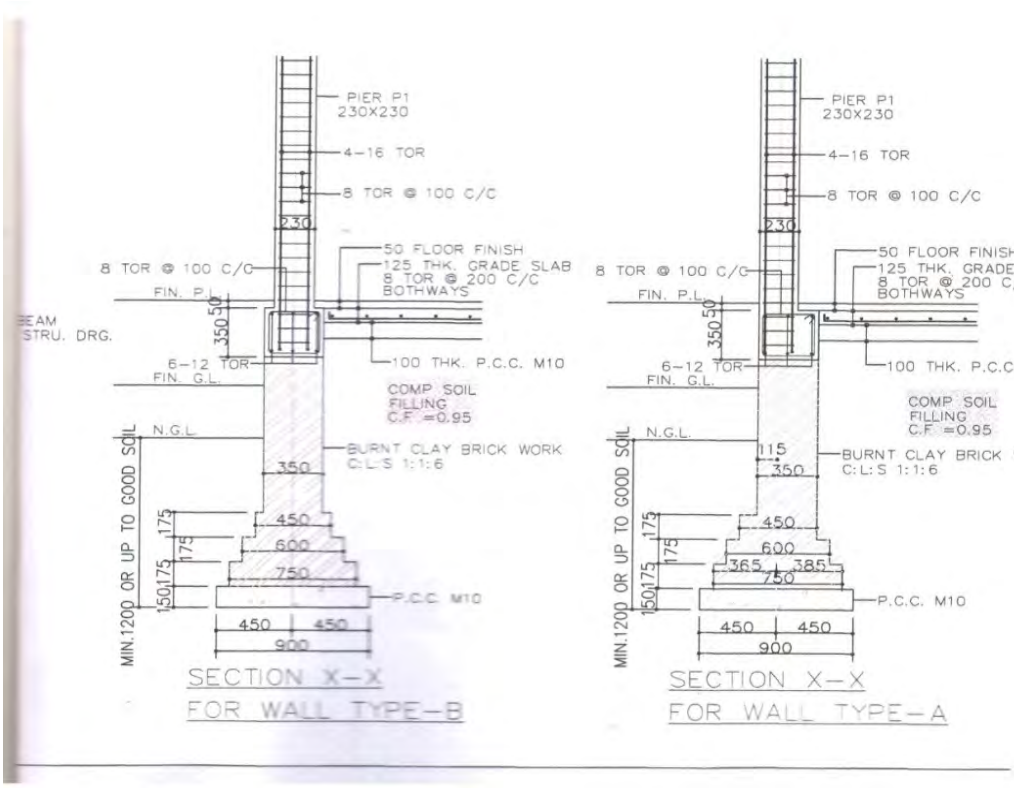


Figure -8: Typical wall foundations adopted for three storey residential building

The three storey residential and four storey hostel buildings under construction are shown in Fig.-9

Fig. 9. Residential and hostel buildings under construction at IIT Gandhinagar, Palaj

15. A comparative study for consumption of cement concrete and steel has been made for a three storey residential block constructed in confined masonry with the same block designed as R C frame structure and is shown in Table 2.

TABLE 2: A comparison of concrete and steel consumption for a three storey apartment

	Description of Item	RC Frame Construction	Confined Masonry Construction	% Reduction
	Concrete (In Cum)			
1	(a) Below Plinth	*416*	*207*	
	(b) Above Plinth	*776*	*603*	
	Total	1192	810	32 %
2	Reinforcement Steel (In Kg)			
	(a) Below Plinth	*20950*	*11845*	
	(b) Above Plinth	*117900*	*79290*	
	Total	138850	91135	34.36 %
3	Brick Work	610	681	

8. CONCLUSIONS

16. Confined masonry buildings have performed well in several earthquake prone areas world over and is this construction typology is in practice due to the following reasons:

- It is based on the traditional masonry construction practice;
- It doesn't require highly qualified labour as in the case of RC frame construction and it is more cost effective mainly due to saving of in concrete and the costly reinforcement steel;
- It has a broad range of applications from single family houses to medium rise apartment buildings

17. Confined masonry construction has a great potential for saving the lives and property in areas of high seismic risk in India and particularly in defense sector where majority of the construction is for low rise buildings spread over in North East and Northern regions of the country. However like any other construction practice, good earthquake performance is based on the good quality materials, workmanship and simple architectural designs.

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