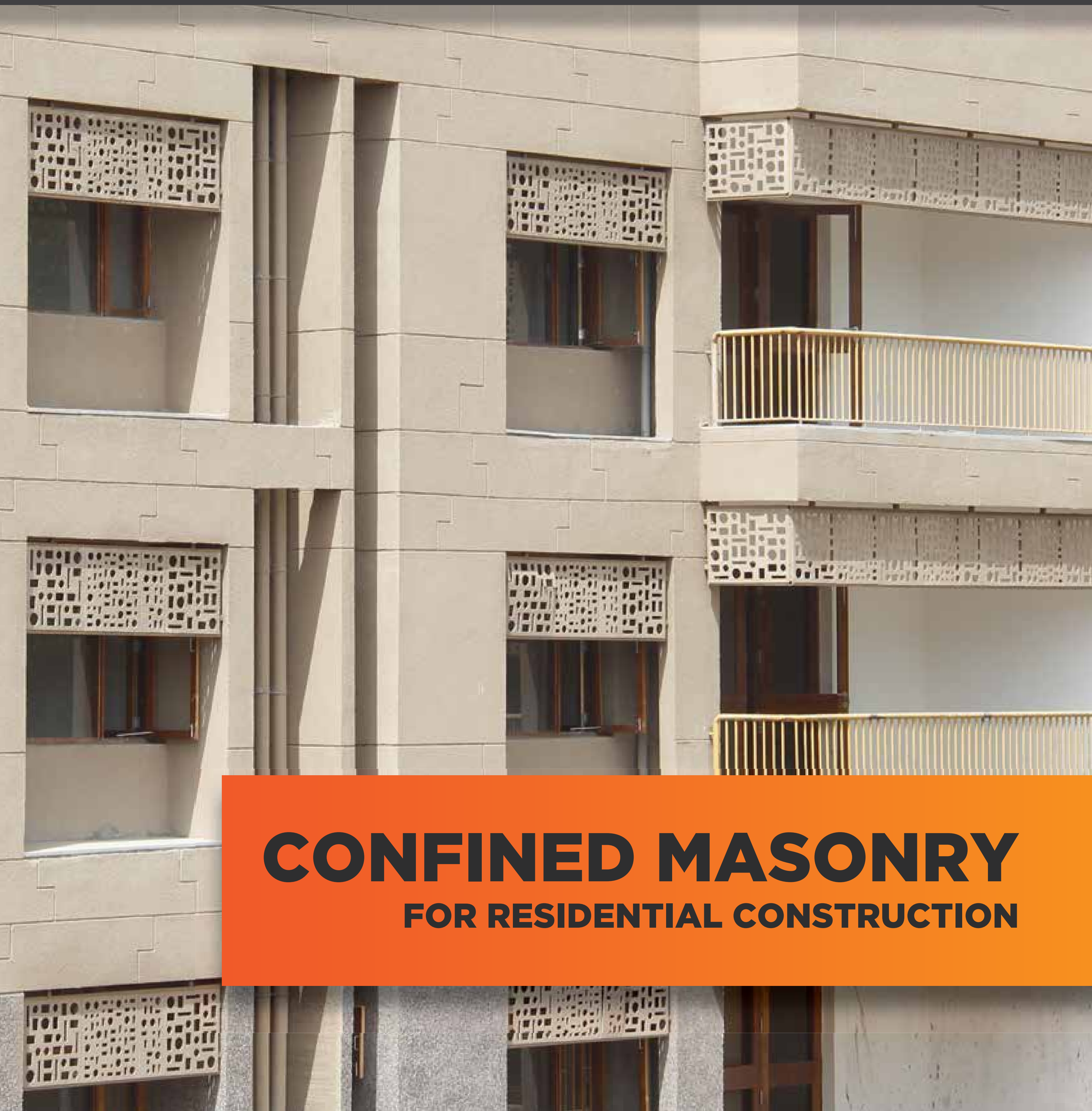
CAMPUS ON THE SABARMATI

IIT GANDHINAGAR



CONFINED MASONRY

FOR RESIDENTIAL CONSTRUCTION

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DISCLAIMER

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FOREWORD

Universities once created last not just decades, but centuries. Hence, it is a rare privilege for any academic to participate in the process of creating a new university. Establishment of the Indian Institute of Technology Gandhinagar (IITGN) has enabled all of us associated with the Institute to innovate in curricula, in governance, and in establishing a unique culture and ethos of the Institute. The philosophy of education has been to push traditional boundaries with an emphasis on multi-disciplinary approaches and crosscutting thematic areas.

Just as the Institute endeavours to think out-of-the-box for its academic programmes and governance, it has also been doing so for development of its 400-acre campus on the banks of Sabarmati River. It is our firm belief that the physical environment makes a huge contribution to shape the processes of learning and knowledge creation. The campus has been conceptualized keeping in mind the long-term objectives as well as the present needs and immediate future. The guiding principles of the campus development have been:

- An ambience that attracts visitors and conveys to them that they are on a university campus unlike any they have visited before.
- Functional convenience for the academic community for mutual interaction, learning and research.
- Low energy and resource consumption, as well as minimal upkeep and low maintenance costs.

Engagement of a large number of professionals and academics in brainstorming and in executing the design and construction has enabled us to introduce numerous innovations in the campus development and this series is meant to describe some of these. One particularly notable innovation is the use of the earthquake-resistant building technology "confined masonry" in the construction of staff housing and student hostels. The focus of this first document is on the use of confined masonry for these thirty-plus housing buildings.

Over the last decade several initiatives have been launched to promote confined masonry construction in India based on its economy, ease of design and construction, and proven record of good seismic performance. The new IITGN campus is the first large-scale systematic application of modern confined masonry construction in India. It is hoped that this monograph will help sensitize and inform building professionals in India and elsewhere about the excellent features of confined masonry, and will propagate a better construction technology in the country and elsewhere.

Sudhir K Jain
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EXECUTIVE SUMMARY

Construction of the IITGN Permanent Campus

In the first instance, the master plan of the IITGN Permanent Campus at Palaj Village, Gujarat, envisaged the construction of 36 confined masonry buildings. This project, building both student hostels and staff and faculty housing, features the first application of engineered confined masonry construction in India for a large-scale project involving public buildings. The campus is on a piece of land on the banks of Sabarmati River measuring about 163 Hectares (399 Acres). The Institute retained a number of reputed consulting firms to carry out the planning and design of student hostels, faculty and staff residences, and academic buildings. Construction began in June 2013 and was executed by a project team of the Central Public Works Department (CPWD).

There are six G+3 (four-storey) hostel buildings with single- and double-occupancy rooms, including three hostels for undergraduate male students, two hostels for graduate students, and one for female students. To house the faculty and staff, 30 G+2 (three-storey) buildings with 270 apartments in total were constructed. There are three types of apartments, with the built up area ranging from 108 to 256 m^2.

Why Confined Masonry?

Confined masonry buildings are expected to have better earthquake performance than unreinforced masonry wall construction and reinforced concrete (RC) frames with infills. The site is located in Seismic Zone III per the Indian seismic code IS: 1893, which implies a shaking intensity of VII (MSK Scale). Gujarat has experienced devastating earthquakes in recent history, including in January 2001 when the Bhuj earthquake (magnitude 7.7; maximum shaking intensity X) struck the Kutch region of Gujarat and caused huge human and economic losses. The death toll was 13,805. Approximately 130 RC frame buildings in Ahmedabad collapsed leading to a death toll of 805.

Evidence from numerous earthquakes in other countries indicates that good seismic performance can be achieved with confined masonry even without a high level of engineering, provided the quality of construction is maintained. For this reason it was decided that residential buildings at the IITGN Permanent Campus would be constructed in confined masonry.

What is Confined Masonry?

Confined masonry is a building technology that uses the same basic materials found in unreinforced masonry construction and RC frame construction with masonry infills, but with a different construction sequence and system. In confined masonry construction, the masonry walls carry the seismic loads and RC confining elements are used to confine the walls. This is in contrast to RC frame buildings with infills where the concrete frames are needed to carry the load. RC frame buildings are much more complex to design and build.

RC confining elements are critical for the earthquake safety of a confined masonry building. These elements are effective in enhancing the stability, integrity, and ductility of the masonry walls and lead to better seismic performance of confined masonry buildings compared to other forms of masonry construction. There are specific rules regarding placement and spacing of these RC confining elements in a confined masonry building that contribute to its better earthquake performance.

Why was Confined Masonry Chosen for this Project?

Confined masonry uses locally available materials and known construction technologies and is particularly appropriate for up to four-storey buildings. It essentially combines two construction technologies that are currently prevalent in the country, masonry and RC. These technologies use locally available materials- cement, steel, and bricks. This is expected to facilitate acceptability of confined masonry technology in the Indian setting.

The residential buildings on campus were ideal candidates for the adoption of the technology in terms of building height (three- and four-storey buildings) and layout, small room sizes, and a significant amount of walls relative to floor area (wall density). Confined masonry construction has also proven to be more economical compared to RC frame construction for the selected buildings.

Design and Construction Challenges in Introducing a New Technology

This is the first large-scale systematic application of confined masonry in India, thus posing several initial design and construction challenges.

Design challenges included the fact that the architectural team was not familiar with features of confined masonry; the structural designers were unfamiliar with analysis and design approaches related to confined masonry structures; and the areas surrounding staircases were not suitable for confined masonry construction, thus those areas were isolated from the adjacent confined masonry construction by means of expansion joints (seismic gaps).

Construction challenges included the need to explain the concept of confined masonry to construction workers as it was critical that they understand the differences between confined masonry and RC frame construction; the need to recruit many workers, as many as 1,400 per day continuously for the first eight months; the need to acquire a significant number of bricks (100,000 bricks/per day), resulting in the setting up of a plant to manufacture Fly Ash Lime Gypsum (FALG) bricks on site.

Building Materials on the Site

Building materials used on the project were typical for RC and masonry construction in India: cement, sand and coarse aggregate, bricks, and reinforcing steel. Maintaining a continuous supply of bricks of required specifications presented a challenge due to the project scale. A few creative approaches were followed to meet these challenges, including building a plant on site to manufacture the FALG bricks that were needed because of their higher compressive strength. Burnt clay bricks were also used; the use of these two different types of bricks was beneficial in expediting the project.

Construction Sequence

The team started the construction process by **clearing the construction site** and beginning the subsequent **foundation construction.** The confined masonry buildings consist of load-bearing walls, hence **continuous brick masonry strip footings were constructed beneath the walls.** Once the footing construction was completed, **the RC plinth band was constructed on top of the foundations.** Longitudinal reinforcing bars in RC tie-columns were placed at the plinth level and anchored into the RC plinth band.

FALG brick masonry walls (230 mm thick) were constructed in two 1.2 to 1.5 m high lifts leaving the space for tie-columns. **Toothing is important for achieving a satisfactory bond between masonry walls and adjacent RC tie-columns in confined masonry construction.** In this project toothing was achieved by extending bricks by about 5 cm in alternate masonry courses along the entire wall height.

Building RC bands is common for load-bearing masonry construction in seismic zones of India. **RC lintel bands were thus constructed** atop the openings (doors and windows) at each storey level.

Once the wall construction was completed up to the certain level, **RC tie-columns** were cast up to the same level (this process was repeated twice for each storey). Finally, **RC tie-beams** were constructed atop the walls once the wall construction was completed up to the soffit level. Concrete for the tie-beams was cast monolithically with the RC floor slab.

Construction Progress and Costs

Preliminary estimates indicate that adoption of confined masonry technology has resulted in a significant cost saving over the RC frame construction.

Construction of the confined masonry buildings was completed in September 2015 (hostels) and January 2016 (apartments).

ACKNOWLEDGMENTS

The authors would like to acknowledge the contributions of all stakeholders in the construction of the IITGN permanent campus: architects and structural designers, Central Public Works Department (CPWD) engineers, contractors, and the construction workers. Special acknowledgment is due to Mr. B. L. Suthar, Executive Engineer and Mr. K. R. Singh, Assistant Engineer, CPWD, for the wholehearted efforts they put into this project. Several IITGN faculty members were also involved in the project from the beginning. The project would not have been possible without the effort and dedication of all these people. This project would also not have been possible without the financial support provided by the Government of India. Some project-related educational activities were sponsored by the Safety Centre at IITGN, and this support is gratefully acknowledged. The authors are grateful to the reviewers: Mr. Andrew Charleson, Victoria University of Wellington, New Zealand and Ms. Marjorie Greene, Earthquake Engineering Research Institute, USA. The authors also appreciate review comments provided by Mr. Christopher Frederick Porst, Master of Science Candidate in Structural Engineering, Massachusetts Institute of Technology, USA. Special thanks are due to Ms. Marjorie Greene for editing the document at the final stages and preparing the Executive Summary.

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1.1. Background

Along with many other new initiatives, the Indian Institute of Technology Gandhinagar (IITGN) became a part of the government-sponsored Indian Institute of Technology system in the 2008-09 academic year. The Institute was initially housed on the premises of Vishwakarma Government Engineering College in Chandkheda, Ahmedabad, Gujarat. In August 2012, the Government of Gujarat provided a piece of land on the banks of the Sabarmati River at Palaj village, Gandhinagar District, measuring about 161 Hectares (399 Acres) to build the IITGN permanent campus. The master plan of the campus is shown in Figure 1.

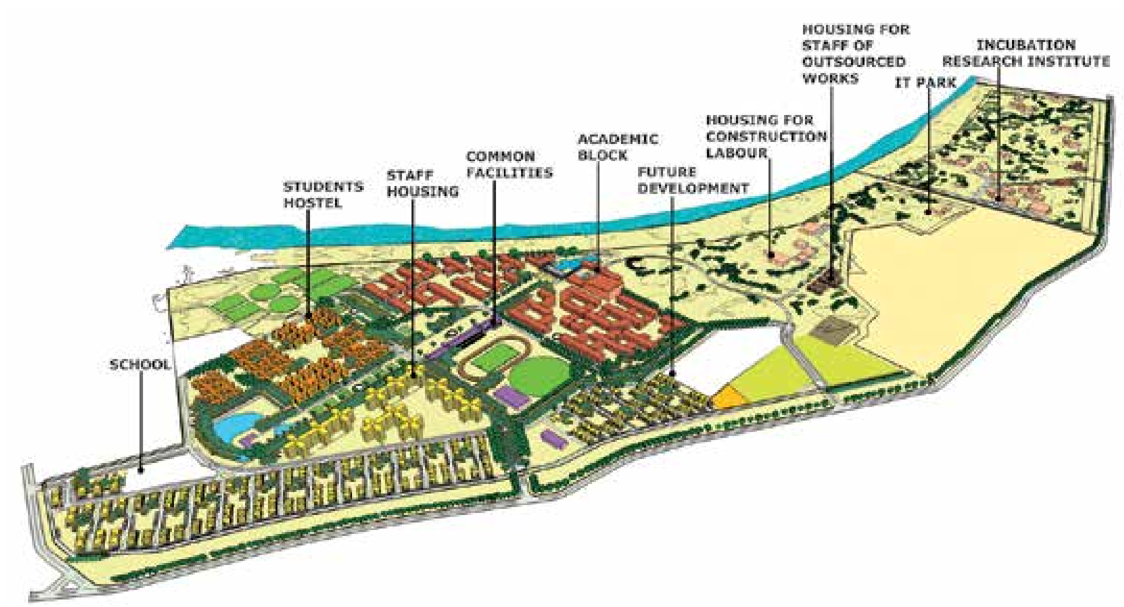


Figure 1. Master plan of the IITGN permanent campus, Palaj Village (Green Campus Development Consortium, New Delhi).

The Institute retained three reputed consulting firms to carry out the planning and design of student hostels, faculty and staff residences, and academic buildings. Construction began in June 2013 and was completed in April 2015. It was executed by a project team of the Central Public Works Department (CPWD).

Construction of the IITGN campus, which is expected to host about 6,000 students, has been divided into two phases. The goal of Phase I (subdivided into Phases IA and 1B) is to develop a fully-residential campus for 2,400 students and associated faculty and staff, while Phase II will encompass construction of the remaining facilities and housing.

Phase 1A of the campus development, which started in June 2013, includes academic buildings, student hostels for 1,200 students, faculty and staff residences, and the related infrastructure. The construction includes approximately 49,270 m^2 of academic area, consisting of G+2 (three-storey) and G+3 (four-storey) reinforced concrete (RC) frame buildings to house laboratories, classrooms, and offices. The academic buildings were constructed using the RC frame system with brick masonry infill walls (Figure 2).

Figure 2. Architectural rendering of campus academic buildings (Mitimitra Consultants).

The remaining buildings on campus, including student hostels and faculty and staff residences, were built using confined masonry construction. There are six G+3 (four-storey) hostel buildings with single- and double-occupancy rooms, including three hostels for undergraduate male students, two hostels for graduate students, and one for female students. In addition, a G+2 dining block was constructed using the RC frame system. The total hostel area under construction is approximately 35,943 m^2 on a land parcel of about 30,000 m^2. An overall view of student hostels is shown in Figure 3, and a typical floor plan is shown in Figure 4.

Figure 3. Architectural rendering of student hostels on campus (HCP, 2014).

Figure 4. Floor plan of a student hostel (HCP, 2014).

To house the faculty and staff, 30 G+2 buildings with 270 apartments were constructed with a total construction area of approximately 49,270 m^2 on a land parcel of about 60,000 m^2. There are three types of apartments, with the built up area ranging from 108 to 256 m^2. An overall view of faculty and staff housing is shown in Figure 5, and a rendering of a typical building is shown in Figure 6. For more details about the IITGN campus construction project refer to Jain et al (2014).

Figure 5. Architectural rendering to provide a view of the faculty and staff residences (Vastu-Shilpa Consultants, 2014).

Figure 6. Architectural rendering of faculty and staff residences (Vastu-Shilpa Consultants, 2014).

This publication is divided into eight sections describing the confined masonry construction process used in the IITGN Permanent Campus project. A special effort has been made to address construction challenges the project team faced, and to provide possible solutions wherever possible. Section 1 introduces the project and explains the basic features of confined masonry construction technology. Section 2 provides an overview of building materials used in the project. Sections 3, 4, and 5 discuss the construction of key building components: foundations, walls, floor and roof slabs. Special emphasis is given to details related to the construction of reinforced concrete confining elements: tie-beams and tie-columns. Section 6 provides information related to the construction progress and the associated costs, including a comparison with reinforced concrete frame construction with masonry infills, which was used for the construction of academic buildings. Section 7 discusses several educational initiatives that have taken place simultaneously with the campus construction. Section 8 offers closing remarks and lessons learned from the project. It is hoped that design and construction teams on future confined masonry building projects in India and other countries will benefit from information provided in this publication.

1.2. What is confined masonry?

After careful consideration, the IITGN project team decided to use confined masonry for construction of 30 G+2 buildings to house IITGN faculty and staff, and six G+3 student hostels. The salient features of confined masonry technology, and a comparison with unreinforced masonry and RC frames with masonry infills, are discussed in this section.

The key components of a confined masonry building are (Figure 7):

1. RC floor and roof slabs – transfer gravity and lateral loads to the walls;

2. Confined masonry walls – transfer lateral and gravity loads from floor and roof slabs down to the foundations. The masonry walls are enclosed on all sides by horizontal and vertical RC confining elements, known as tie-beams and tie-columns; these RC elements provide confinement to the masonry walls and protect them from collapse in major earthquakes;

3. RC plinth band – transfers the loads from walls to the foundation system and reduces differential settlement; and

4. Foundation – transfers the load to underlying soil.

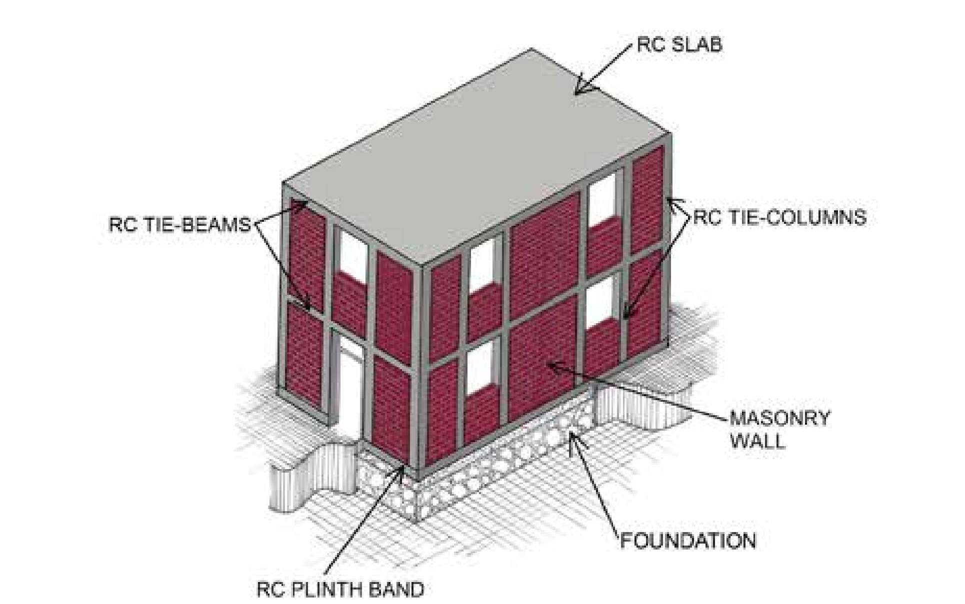


Figure 7. Key components of a confined masonry building (Brzev, 2008).

RC confining elements are critical for the earthquake safety of a confined masonry building. These elements are effective in enhancing the stability, integrity and ductility of masonry walls subjected to in-plane and out-of-plane seismic excitation. They are expected to lead to enhanced seismic performance of confined masonry buildings compared to unreinforced masonry construction.

There are specific rules regarding placement and spacing of RC confining elements in a confined masonry building. For example, vertical RC confining elements, also known as tie-columns, should be provided at wall intersections, door and window openings, free ends of the walls, and at intermediate locations in long walls (usually at a maximum of 4 m spacing), as shown in Figure 8.

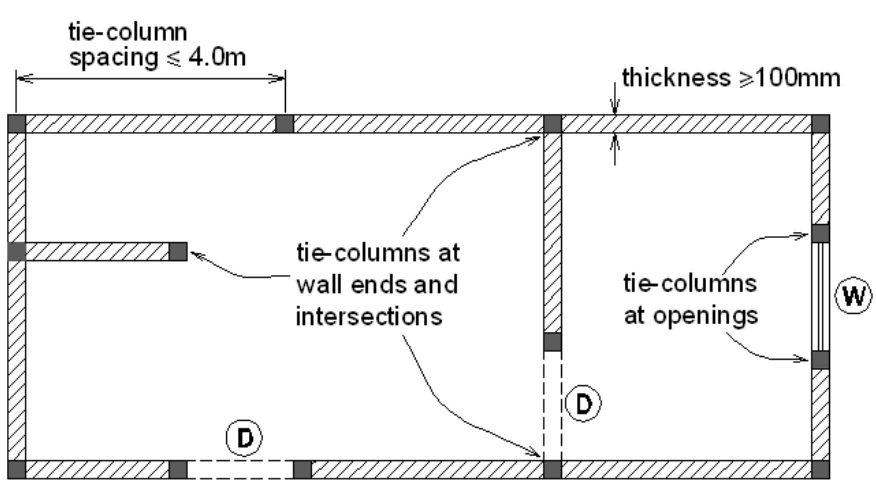


Figure 8. A sample floor plan of a confined masonry building (Brzev, 2008).

Masonry walls in a confined masonry building act integrally with the RC confining elements. This integral action is possible due to the unique construction sequence characteristic of confined masonry building technology. The four key steps related to construction of confined masonry walls are explained below:

1. Longitudinal reinforcing bars in RC tie-columns are placed at the plinth level and anchored into the RC plinth band (Figure 9).

2. Masonry walls are constructed between tie-columns (Figure 10) with toothing at either end (Figure 11). As an alternative to toothing, horizontal reinforcing bars (dowels) can be provided at wall-to-tie-column interface.

3. RC tie-columns are then cast (Figure 12). The entire panel height is usually constructed in two 1.2 to 1.5 m high lifts (Figure 13).

4. RC tie-beams are constructed atop the walls once the wall construction is completed up to the total storey soffit level (Figure 14). Concrete for the tie-beams is cast monolithically with the floor slab (Figure 15).

Figure 9. Tie-column longitudinal reinforcement at the plinth level.

Figure 10. Masonry wall between adjacent tie-columns (construction in progress).

Figure 11. Toothing at the wall-to-tie-column interface.

Figure 12. Concrete construction completed at lower portion of a RC tie-column.

Figure 13. Formwork in place at upper portion of a RC tie-column.

Figure 14. Formwork for tie-beams.

Figure 15. Tie-beam and slab reinforcement.

It is important to understand that confined masonry is a loadbearing wall structural system, where walls are the critical structural components that resist gravity loads and also lateral loads due to wind and earthquakes. Masonry walls are usually unreinforced in low-rise confined masonry buildings (one- and two-storey high). In taller buildings horizontal reinforcement may be required to resist earthquake-induced shear stresses. Horizontal RC confining elements (tie-beams) provided at the floor and roof levels and continuous, well placed vertical RC confining elements (tie-columns) are effective in preventing collapse and human losses in earthquakes. The satisfactory performance of confined masonry buildings constructed in this manner has been observed in past earthquakes in many countries. These include major earthquakes, such as the 2010 Maule, Chile earthquake (Magnitude 8.8); 2007 Pisco, Peru earthquake (Magnitude 8.0); and several earthquakes in Indonesia, including the 2004 Great Sumatra Earthquake and Indian Ocean Tsunami (Magnitude 9.0). Refer to EERI (2011) for more information on the performance of confined masonry buildings in past earthquakes.

Unreinforced masonry construction has been traditionally practiced in India for many centuries. Design applications range from single-storey rural houses to four-storey residential buildings in urban centres. Walls in these buildings are usually constructed using burnt clay bricks in cement, cement:lime (a mix of cement and lime), or mud mortar. General provisions for the design of unreinforced masonry buildings are covered in IS:1905, and the seismic design of these buildings is addressed by Indian seismic codes (IS:1893 and IS:4326). According to IS:4326, continuous horizontal RC bands are a key seismic design requirement for masonry buildings located in seismic zones III to V of India. These bands may be provided at a combination of plinth, sill, lintel and roof levels at every floor in a building, depending on the seismic zone and other criteria (Figure 16). The bands enhance earthquake safety by ensuring integral box-like action of a building and preventing the collapse of masonry walls due to out-of-plane seismic effects (earthquake shaking perpendicular to wall surface) provided that adequate wall-to-floor connections are constructed.

The effectiveness of RC lintel bands in improving the seismic performance of masonry buildings was confirmed in past earthquakes in India, including the 1993 Killari, Maharashra earthquake (Magnitude 6.2) and the 2001 Bhuj, Gujarat earthquake (Magnitude 7.7). However, in countries with a long history of confined masonry construction practice including Mexico, Chile, and Peru, confined masonry buildings are constructed without RC bands at lintel and sill levels. These buildings have performed well in many damaging earthquakes over the last few decades. In those countries, provision of RC tie-beams at the floor and roof levels is considered sufficient to ensure building integrity during an earthquake (in conjunction with other seismic resistant features); this is particularly true for buildings with RC floor and roof slabs. These RC tie-beams can be considered equivalent to RC roof bands. It should be noted that RC lintel bands may be useful for enhancing resistance to out-of-plane seismic loading in walls with large openings and walls with large slenderness (height/thickness ratio).

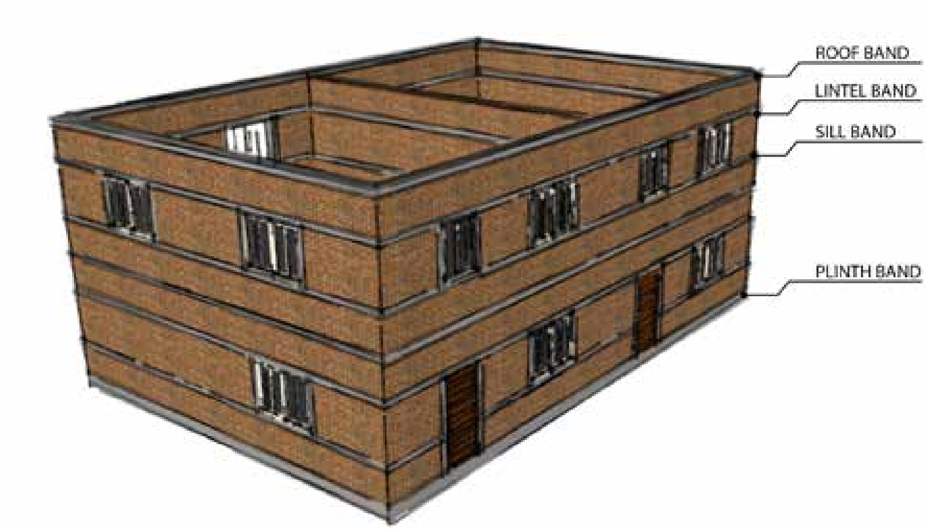


Figure 16. Required seismic bands for masonry buildings in Seismic Zone V in India according to IS:4326.

Considering the fact that this project is the first large-scale application of confined masonry for engineered buildings in India, the project team decided to provide continuous RC lintel bands in all stories. It should be noted that the floor height (clear distance between floor slabs) exceeded 3 m in all buildings. The team also provided RC plinth bands in all buildings; this is a common practice in confined masonry construction.

A completed confined masonry building looks similar to a RC frame building with masonry infill walls, however there is a significant difference in the construction sequence between these two construction technologies. In a confined masonry building masonry walls are constructed first, as shown in Figure 17, while in a RC frame building with masonry infills the frame is constructed first (Figure 18).

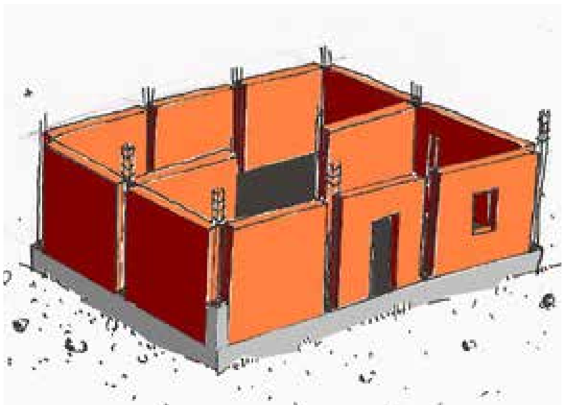


Figure 17. Confined masonry building under construction (Source: T. Schacher).

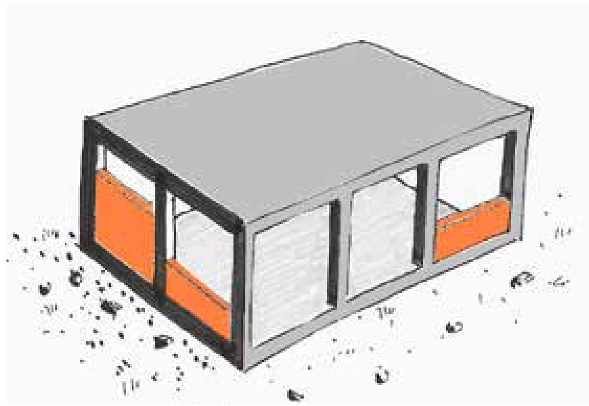


Figure 18. RC frame building with masonry infills (Source: T. Schacher).

It is important to note that, unlike infill walls in a RC frame building, confined masonry walls are loadbearing. RC tie-columns are not expected to sustain significant gravity loads, hence these elements are smaller in size than columns in a RC frame structure. Figure 19 shows a comparison between an RC frame with masonry infills and a confined masonry wall.

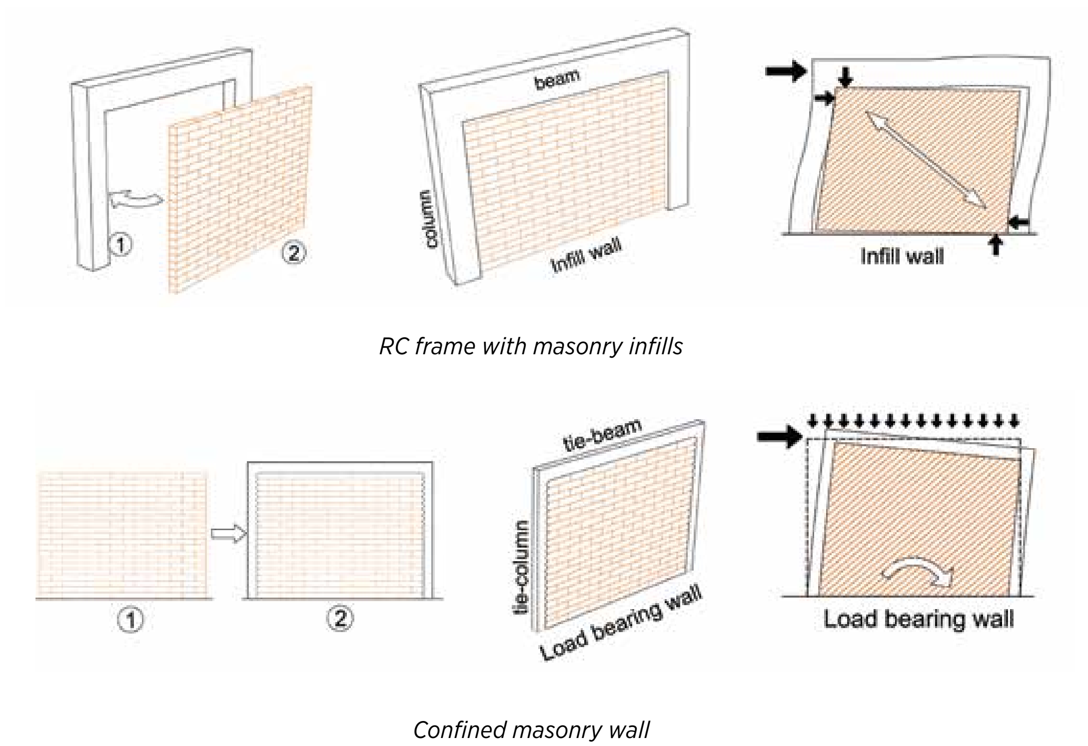


Figure 19. Comparison of a RC frame with masonry infills and a confined masonry wall (EERI, 2011).

For more information related to confined masonry design and construction refer to publications by Brzev (2008), Schacher (2009), EERI (2011) and Murty (2013).

1.3. Why was confined masonry chosen for this project?

Confined masonry was chosen for this project for the following reasons:

1. ***Confined masonry buildings are expected to have better earthquake performance than unreinforced masonry wall construction and RC frames with infills.***

   The site is located in Seismic Zone III per the Indian seismic code IS:1893, which implies a shaking intensity of VII (MSK Scale). Although Zone III is considered as moderate seismicity per IS:1893, seismic design provisions are required for buildings in this zone. It is also worth noting that Gujarat has experienced devastating earthquakes in its recent history. In January 2001, the Bhuj earthquake (magnitude 7.7; maximum shaking intensity X) that struck the Kutch area of Gujarat caused huge human and economic losses. The death toll was 13,805 and over 167,000 people were injured, while the estimated economic loss was Rs. 22,000 crores (US$ 4 Billion). Both older masonry buildings and modern RC buildings were affected by the earthquake. Approximately 130 RC frame buildings in Ahmedabad collapsed leading to a death toll of 805.

   Evidence from numerous earthquakes in other countries indicates that good seismic performance can be achieved with confined masonry even without a high level of engineering, provided the quality of construction is maintained.

2. ***Confined masonry uses locally available materials and known construction technologies, that is, unreinforced masonry walls and reinforced concrete frames and slabs.***

   It was anticipated that the introduction of this new technology in India would pose a challenge. However, confined masonry essentially combines two construction technologies that are currently prevalent in India, namely, masonry and RC. These technologies use locally available materials like cement, steel and bricks. This was expected to facilitate acceptability of confined masonry technology in the Indian setting, provided that construction workers are given training at the initial stage.

3. ***Hostels and faculty and staff residences were suitable for the application of confined masonry.***

   Residential buildings were ideal candidates for the adoption of the confined masonry technology in terms of building height (three- and four-storey buildings) and layout, small room sizes, and a significant amount of walls relative to floor area (wall density).

4. ***Confined masonry construction was expected to be more economical compared to reinforced concrete frame construction for the selected buildings.***

   Based on preliminary estimates, the application of confined masonry was expected to lead to significant cost savings compared to RC frame construction.

1.4. Design and construction challenges in the planning stage

Considering that this is the first reported wide-scale application of confined masonry in India, it is no surprise that the project team initially faced several design challenges, including:

1. The architectural team was not familiar with the features of confined masonry buildings in terms of layout and planning. The buildings were originally designed following planning concepts for RC frame construction, therefore the design had to be modified to accommodate confined masonry.
2. The structural designers were unfamiliar with analysis and design approaches related to confined masonry structures, and they treated confined masonry buildings as RC frame structures which require

ductile detailing per IS:13920. Moreover, the civil engineering curriculum in most colleges and universities in India does not include structural design of masonry buildings.

3. The project team used available guidelines from India and abroad (Brzev, 2008; EERI, 2011) and results from research studies (e.g. Singhal and Rai, 2014), with due modifications related to site seismicity and material properties.

4. Areas surrounding staircases were not suitable for confined masonry construction. Therefore, those areas were treated as free-standing RC frame systems and were isolated from the adjacent confined masonry construction by means of expansion joints (seismic gaps). Expansion joints were also used in a few buildings with complex plan shapes to create simple rectangular segments and minimize torsional effects.

Construction challenges:

1. Difference between confined masonry and RC frame construction. The most significant challenge was explaining the concept of confined masonry to construction workers. It was essential to explain the differences between confined masonry and RC frame construction. RC frame construction is common in India and workers are familiar with it, but it was difficult to teach them a construction technology that looks similar and uses the same materials, but structurally behaves quite differently. It was also challenging to explain some confined masonry construction features (e.g. toothing) that are critical for seismic safety of these buildings. To ensure satisfactory construction quality, training camps for masons were organized at the construction site.

2. Masonry construction is labour-intensive. It was challenging to recruit both the required number of unskilled and skilled labourers. The total required number of workers varied. On average 1,400 workers per day were required continuously for the first eight months.

3. The project required a significant brick supply (about 100,000 bricks/day). The required properties were a compressive strength of 9 MPa and water absorption of less than 14%. A preliminary survey showed that traditional burnt clay bricks manufactured in the Gandhinagar and Ahmedabad districts and nearby areas generally did not possess these characteristics. Therefore, a plant for manufacturing Fly Ash Lime Gypsum bricks was set up at the construction site.

2 Building Materials

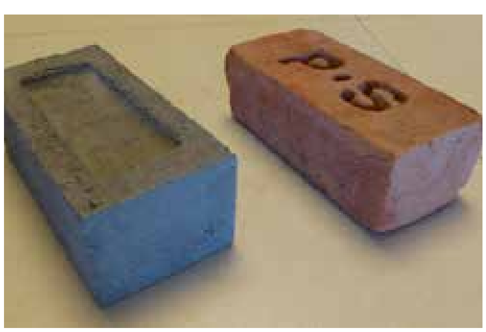
Building materials used for the project were typical for reinforced concrete and masonry construction in India: cement, sand and coarse aggregate, bricks, and reinforcing steel. Maintaining a continuous supply of these materials at the site presented a challenge due to the project scale. A few creative approaches were followed to meet these challenges. This section describes the key characteristics and methods of manufacturing and acquiring building materials used on the project.

2.1. Bricks

Virtually every building on the campus required bricks for masonry construction. Staff housing and student hostels are load-bearing confined masonry structures, while academic buildings are RC frame structures with brick masonry partition and exterior walls. Higher compressive strength bricks were required for above grade confined masonry construction, but lower strength bricks were acceptable for foundation construction and masonry infills in RC frame buildings. As a result, there was a significant demand for bricks - on the order of 100,000 bricks per day. A preliminary survey of local brick manufacturers performed by CPWD engineers showed that it was not possible to procure a sufficient amount of clay bricks of the required quality in the Ahmedabad area. For this reason it was decided to use special Fly Ash Lime Gypsum (FALG) bricks due to their availability and higher compressive strength. The project team set up a plant for manufacturing FALG bricks (capacity 65,000 bricks/day) at the construction site. The bulk quantity of fly ash needed was available from nearby thermal plants. Clay bricks and FALG bricks used on the IITGN project are shown in Figure 20.

FALG bricks had a higher compressive strength than burnt clay bricks, however they also had higher water absorption; this was a concern for below grade masonry applications. Therefore, FALG bricks with a class designation 9.0 MPa as per CPWD Specifications and a maximum 12% water absorption were used for above grade construction, while foundations below the plinth level were constructed using burnt clay bricks with a minimum compressive strength of 5.0 MPa and a maximum 15% water absorption. FALG brick properties were in compliance with IS 12894:2002, and regular testing was performed in a laboratory set at the manufacturing plant.

The use of two different sources for brick supply was also beneficial for expediting the project. The manufacturing process is illustrated in Figure 21. Initial testing of the mechanical and physical properties of the bricks used on the project was performed at IIT Kanpur (Rai, 2013).



A typical FALG brick (left) and a clay brick (right)

Clay bricks at the construction site

Figure 20. Clay bricks and FALG bricks at the IITGN construction site.

FALG brick manufacturing plant

Brick manufacturing machine

Brick supply at the plant

FALG bricks at the construction site

Figure 21. Manufacturing process for FALG bricks at the IITGN campus construction site.

2.2. Mortar

Brick masonry construction was performed using 1:1:6 cement:lime:sand mortar, which is Type M1 mortar according to the IS:1905 standard. Mortar was mixed using a mechanical mixer. Fresh mortar had to be used within 2 hours of mixing.

Hydrated Lime Class ‘C ‘in the form of a fine dry powder conforming to IS:712 standard was used on the project. The lime was procured from the State of Rajasthan (Figure 22).

Portland Pozzolana Cement (PPC) conforming to IS:1489 (Part I) with a fly ash content of 28% or more was used on the project. Cement for masonry and concrete construction was supplied in 50 kg bags (Figure 23).

Figure 22. Lime powder used for construction.

Figure 23. Cement bags at a storage facility.

Coarse sand was sourced from the Sabarmati River up to 10 km away from site (Figure 24). The sand had to be clean from organic impurities. If the sand brought to the site was dirty, it had to be washed in clean water to bring it to the required specifications. Coarse sand was screened before it was used for construction.

Figure 24. Sand supply at the construction site.

2.3. Concrete

Concrete of grade M25 conforming to IS:456 was used on the project. The characteristic compressive strength was 25 MPa based on 15 cm cube specimens tested at 28 days. A minimum 300 kg cement per m^3, and water/cement ratio of 0.5 or less were specified. The required slump was 50 to 100 mm for tie-columns and 30 to 50 mm for tie-beams. A concrete batch mix plant with 60 m^3/hr capacity was set up at the site (Figure 25).

Figure 25. Concrete batch mix plant.

2.4. Steel

High strength TMT bars (Fe500D grade) complying with the IS:1786 standard were used for the reinforced concrete construction (500 MPa yield strength). Smaller bar sizes (8 mm) were used for ties in tie-beams and tie-columns, while 10, 12, and 16 mm bars were used for longitudinal reinforcement (Figure 26). The steel was brought to the site in bulk supply (100 tonnes or more). The steel was sourced from primary producers who manufacture rebar from ingots.

a) Steel delivered at the construction site

b) Steel reinforcement cages assembled at the site

Figure 26. Steel reinforcement as delivered at the campus site.

3 Foundation and Plinth Construction

The team started the construction process by clearing the construction site and beginning the subsequent foundation construction. The confined masonry buildings consist of load-bearing walls, hence they have continuous strip footings beneath the walls. The key stages of foundation construction are described below.

3.1. Site preparation

Site preparation was performed by clearing the ground and subsequently laying the outline of the individual buildings. The site was previously unoccupied, and it was covered with grass, shrubs, and undulations which had to be removed (Figure 27). However, all larger trees found at the site were preserved during the construction.

Figure 27. IITGN campus site before construction - note thermal power plant at the far right (April 2013).

Geotechnical investigations were performed to determine soil properties for foundation design. The plate load test method was used to determine the ultimate soil bearing capacity and settlement under a given load (Figure 28). Soil investigations were performed by the IITGN geotechnical engineering faculty and students (Sachan, 2012).

Figure 28. Test setup for geotechnical investigations.

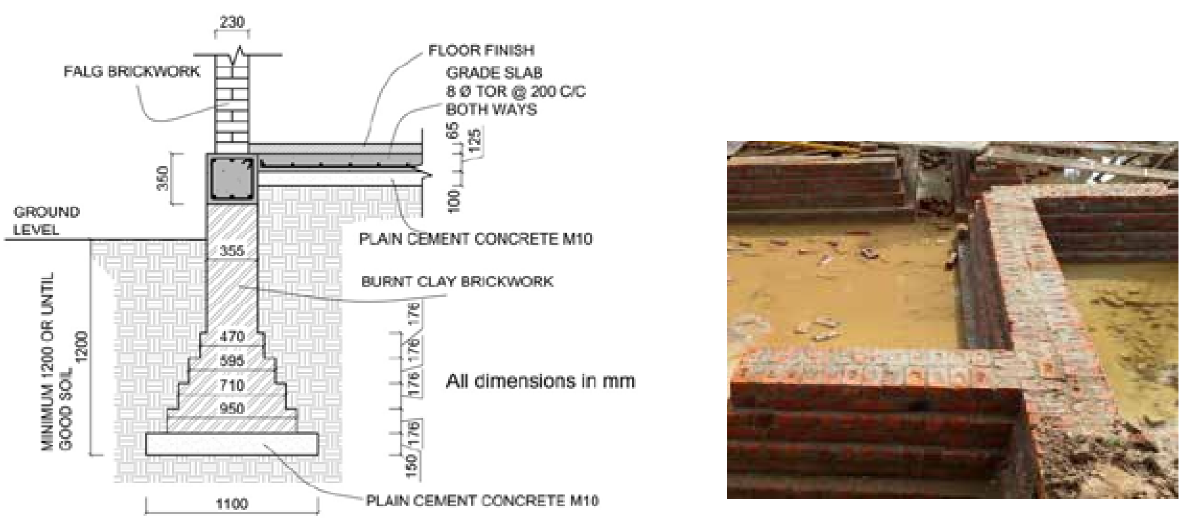
3.2. Excavation

Once the site was cleared, foundation plan dimensions were marked on the ground and batter boards were erected (Figure 29). Tracing wires were fixed on batter boards along the trenches to indicate the foundation profile. Trenches were marked on the ground using a plumb line and chalk. After being marked, the trenches were excavated to the foundation depth. A 1.5 m foundation depth was specified for confined masonry buildings (housing and hostels); this was deemed appropriate for the given soil conditions. After the excavation was completed, the bottom of each trench was compacted with a rammer and levelled.

Figure 29. Construction workers marking foundation plan dimensions at the cleared ground.

3.3. Wall footings

The trenches were filled with a 150 mm thick bed of Plain Cement Concrete (PCC) with M10 grade (lean concrete) which formed the base for foundation construction. Once the PCC bed was set and cured, the construction of wall footings proceeded using burnt clay bricks and 1:1:6 cement:lime:sand mortar. The lower portion of the foundation (700 mm deep) was wider and it consisted of eight courses of tapered brick masonry, with the width ranging from 900 mm at the base to 350 mm at the top. The upper portion of the foundation up to the plinth level was 350 mm wide (corresponding to 230 mm wall thickness), as shown in Figure 30. Masonry construction at the foundation level is illustrated in Figure 31.



a) b)

Figure 30. Brick masonry foundations: a) a vertical section, and b) foundation construction.

Figure 31. Construction at the plinth level - mortar preparation.

3.4. RC plinth band

Once the footing construction was completed, the RC plinth band was constructed continuously beneath the walls, as shown in Figure 32. The plinth band cross-sectional dimensions were 350 mm square, and the reinforcement consisted of six 12 mm diameter longitudinal reinforcing bars and 8 mm closed ties at 100 mm spacing c/c with 135 degree hooks. First, the reinforcement cages were laid in position. Next, vertical reinforcement for the RC tie-columns was erected from the plinth level and anchored into the plinth bands. Once the reinforcement was laid, shuttering was erected on each side along the band. After the concrete was poured, the plinth band was cured for 7 days before the wall construction began.

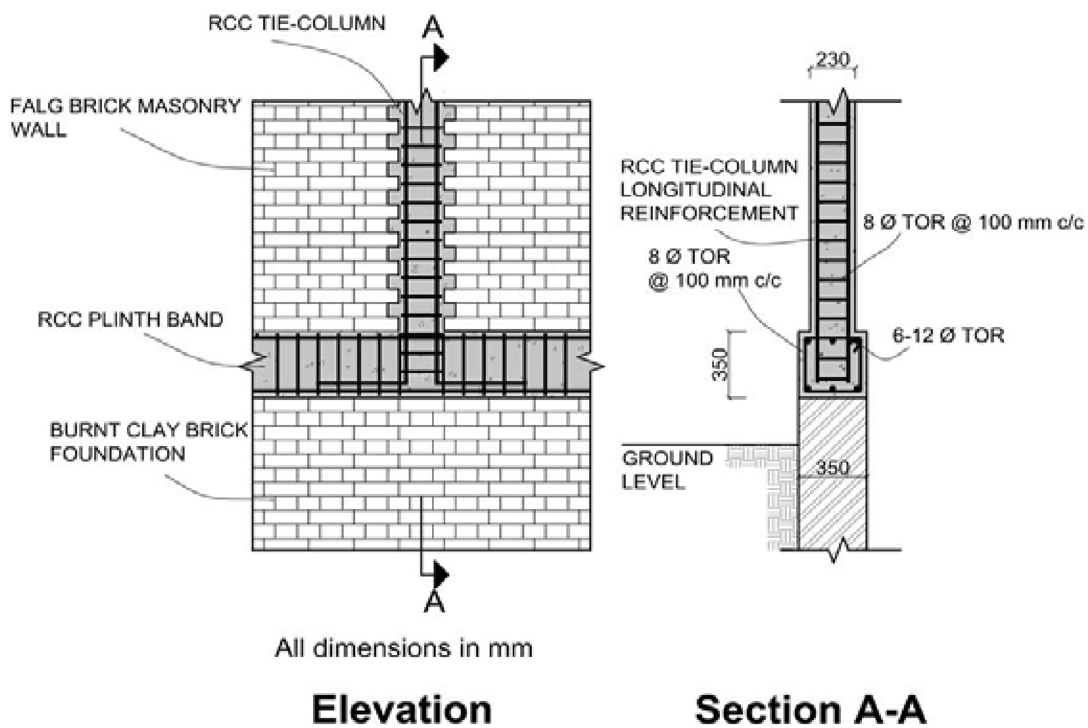


Figure 32. RC plinth band elevation and a cross-section.

RC tie-columns are a unique feature of confined masonry construction. In order to ensure composite action of masonry walls and adjacent RC tie-columns, longitudinal reinforcement in tie-columns needs to be anchored at the foundation level. In this project, the longitudinal reinforcement was anchored into the plinth band using 90 degree hooks extended into the plinth band by 450 mm, as shown in Figure 32. Plinth band construction is illustrated in Figure 33.

Construction challenges:

Footing for RC tie-columns. The project team debated whether the RC tie-columns require column footings similar to RC frame construction, or whether it would be adequate to start tie-column construction at the RC plinth band level. The latter alternative was pursued to expedite the construction process and minimize foundation costs. For that reason, the size of the RC plinth band was more robust than what it would have been otherwise.

Plinth band reinforcement cage set in place

Formwork for plinth band construction

Tie-column longitudinal reinforcement anchored into plinth band

Plinth level in a building showing tie-column reinforcement extending above the plinth band

Figure 33. Plinth band construction and tie-column longitudinal reinforcement.

4 Construction of Confined Masonry Walls

4.1. Confined Masonry Walls

Masonry walls were constructed on top of the RC plinth band (at the ground floor level) or the RC slabs (at upper storey levels). The wall construction process is described below.

4.1.1. Transporting bricks at the construction site

Bricks were first transported from the manufacturing plant to the construction site, and were subsequently moved by construction workers to various wall construction locations, as shown in Figure 34.

Figure 34. Transporting bricks at the construction site.

4.1.2. Preparing bricks for construction

The bricks were immersed in water for 24 hours before construction to minimize chances of absorbing water from fresh mortar, as shown in Figure 35.

Figure 35. Bricks immersed in water before construction.

4.1.3. Mortar Preparation

Mortar was prepared according to the specified mix design, that is, 1:1:6 cement: lime: sand ratio. Mixers were used to mix mortar at the construction site, as shown in Figure 36. Water was added to the mix to ensure that mortar was workable and ready for construction.

Figure 36. Mortar mixing at the construction site.

4.1.4. Masonry construction

The confined masonry walls were 230 mm thick (one brick thick) and were constructed in English bond. The wall construction began with laying of a mortar bed on the roughened horizontal surface in a 10 to 12 mm thick layer. The mortar was used within 2 hours from preparation, allowing for tempering to compensate for lost water due to evaporation. The bricks were lightly tamped while being placed in position. Next, mortar was applied on vertical brick faces to create head joints. A 10 to 12 mm thick horizontal mortar bed joint was laid on top of the brick course. The masonry wall construction is illustrated in Figure 37.

Mason laying a mortar bed joint

Wall construction at higher elevations

Figure 37. Masonry construction in progress.

4.1.5. Toothing at the wall to tie-column interface

Toothing is important for achieving a satisfactory bond between masonry walls and adjacent RC tie-columns in confined masonry construction. In this project toothing was achieved by extending bricks by about 5 cm in alternate masonry courses along the entire wall height, as shown in Figure 38. Examples of a toothed wall-to-tie-column interface are presented in Figure 39. It can be somewhat challenging to achieve toothing at wall intersections, as illustrated in Figure 40. An example of construction specification for toothing at cross wall intersection is presented in Figure 41. The opening in brickwork shall be kept at 288 x 288 mm size in each direction, and toothing will need to be provided in alternate courses.

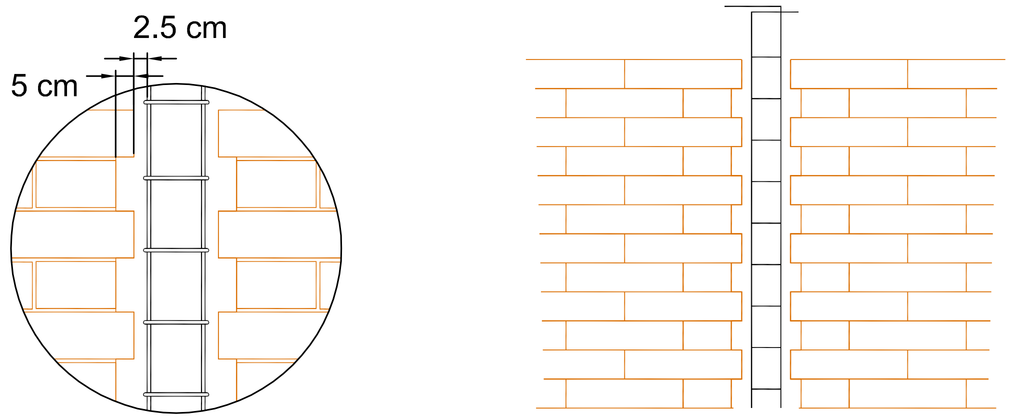


Figure 38. Toothed interface between two interior brick masonry walls (EERI, 2011).

a) Toothed wall edges at an interior tie-column

b) Toothed wall edges at a corner tie-column

Figure 39. Examples of toothing at the IITGN campus site.

Figure 40. Toothing at cross wall intersections.

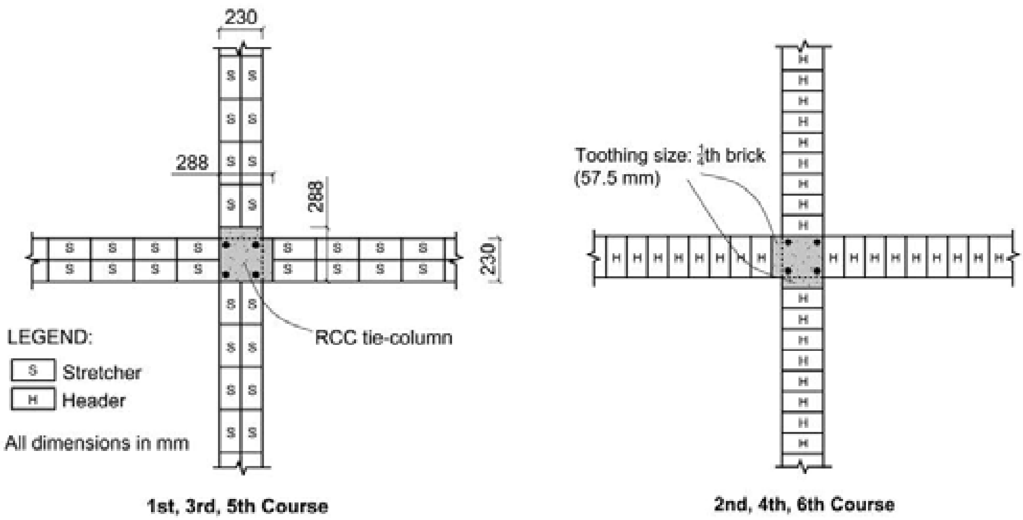


Figure 41. Locations of RC tie-columns and masonry wall layout at a cross wall intersection: construction specification.

Construction challenges:

Toothing size. Initially, the goal was to achieve a toothing size of more than 5 cm, but after several attempts it was concluded that 5 cm is the maximum that can be achieved while still ensuring that the toothed interface is filled with concrete.

4.1.6. Wall construction stages

The construction specification prescribed that 1.5 m of wall height (approximately one-half of the overall storey height) was to be constructed in one lift, followed by casting of RC tie-columns (see Figure 42). Subsequently, the construction had to be suspended for 3-4 days for the wall to achieve sufficient strength so that the concrete for the tie-columns could be poured. This procedure was repeated at each storey level.

Wall construction completed up to 1.5 m height (one lift)

Tie-column construction completed up to 1.5 m height

Figure 42. Sequence of wall and tie-column construction.

4.1.7. Reinforced concrete lintel bands

Building RC bands is common for load-bearing masonry construction in seismic zones of India. RC lintel bands were constructed atop the openings (doors and windows) at each storey level. First, reinforcement cages were assembled on the ground, as shown in Figure 43. Subsequently, formwork was set in place and concrete was poured, as shown in Figure 44. The upper courses of the brick masonry wall beneath the band had to be wetted before the concrete was poured to prevent the bricks from absorbing water from the fresh concrete. Curing of the concrete was the final activity in the band construction.

Figure 43. Construction workers assembling reinforcement cages for RC lintel bands.

Reinforcement cages set in place　　*Formwork for lintel bands*

Figure 44. Construction of RC lintel bands.

4.1.8. Masonry and RC-tie-column construction above the lintel band level

The final stage of the masonry wall construction at each storey comprised of laying a few courses of masonry above the lintel level, and casting concrete for the portion of the tie-column between the RC lintel band and RC tie-beam (Figure 45).

Figure 45. Confined masonry wall under construction - note a completed RC lintel band and RC tie-beam at the floor level and formwork for tie-columns above the lintel band.

Construction challenges:

Lintel band. After the lintel band was completed (concrete was cast and hardened for 3 to 4 days), a few more courses of masonry had to be laid before the RC tie-beams were constructed on top of the wall. This slowed down the construction progress. It would have been more efficient to construct this portion in reinforced concrete.

4.1.9. Curing of masonry walls

The curing of masonry walls lasted 7 days after the construction was completed. It was performed three times a day by wetting the wall surface with water applied through a hose (Figure 46).

Figure 46. Curing of masonry walls.

4.2. Reinforced concrete Tie-columns

RC tie-columns are structural components unique to confined masonry construction. These components act in unison with the masonry walls to ensure the seismic safety of a confined masonry building. In this project cross-sectional dimensions were 230 mm square to match the wall thickness. The tie-column construction process is described below.

4.2.1. Tie-column reinforcement

Tie-columns were reinforced with longitudinal (vertical) reinforcement and transverse reinforcement (ties). Longitudinal reinforcement in the tie-columns consisted of 4 high strength TMT steel bars of 12 to 16 mm diameter (depending on the location). The reinforcement was anchored in the RC plinth band and extended vertically for about 4 m (more than a storey height), as shown in Figure 47.

a) Plinth level

b) Upper floor levels

Figure 47. Longitudinal reinforcement for RC tie-columns.

Transverse reinforcement in the form of ties was placed in tie-columns before the masonry wall construction started (Figure 48). In general, 8 mm diameter bars were placed at 100 to 150 mm on centre spacing, depending on the location. The ties had 135 degree hook terminations to ensure superior anchorage and prevent tie-column failure in earthquakes. Although tie arrangement in tie-columns and RC columns may look similar, detailing requirements for ties in tie-columns are more relaxed since these components are an integral part of a confined masonry loadbearing wall system. For that reason, it is not required to follow ductile detailing requirements for RC frames contained in IS:13920.

Figure 48. Transverse reinforcement (ties) for RC tie-columns - note 135 degree hooks.

Construction challenges:

Detailing of tie-columns and tie-beams. Initially, the structural engineer insisted on treating confined masonry buildings as RC frame structures which require ductile column and beam detailing per IS:13920. This resulted in excessively close spacing of ties in tie-columns and posed a construction challenge – it was difficult to place concrete in tie-columns. It took an effort to convince the structural engineer that tie-columns and tie-beams are not the same as members of moment resisting frames.

4.2.2. Construction sequence

Casting the concrete in RC tie-columns at each storey level was done in two stages. First, a masonry wall was constructed up to the specified height equal to approximately one-half of the storey height. Next, concrete was poured to the same height in adjacent tie-columns (Figure 48). The same process was repeated after the masonry wall construction was completed up to the full storey height.

a) RC tie-columns before formwork was set in place

b) Formwork for RC tie-columns set in place

Figure 49. Tie-column construction.

Construction challenges:

Construction speed. Concrete in the tie-columns had to be poured 3 to 4 days after masonry walls were built to allow masonry to attain the required strength; this slowed down the construction progress.

Also, construction trades involved in building masonry walls were different from those involved in concrete construction. Therefore, it took time to change shifts; this caused a further slowdown.

Eventually, to speed up construction, the walls were constructed to full height in one lift and then concrete for the tie-columns was poured. This was done at later stages of the IITGN project at selected locations.

4.2.3. Shuttering

Column shuttering was placed in position on two faces of an interior tie-column, while the masonry acted as shuttering on the remaining two faces. Shuttering was extended by 25 to 50 mm beyond the toothing on the wall. It had to be fixed properly in position to maintain the required shape and size of the tie-columns. The shuttering faces were joined together using a mix of clamps and steel wire ties. Also, nails were driven into bricks to attach formwork to the masonry walls (Figure 50).

a) Shuttering in place at an interior tie-column

b) Steel wire ties were used to fix shuttering in place

c) Masonry wall surface showing a hole in a brick created to secure the formwork in place

Figure 50. Formwork and shuttering for RC tie-columns.

Construction challenges:

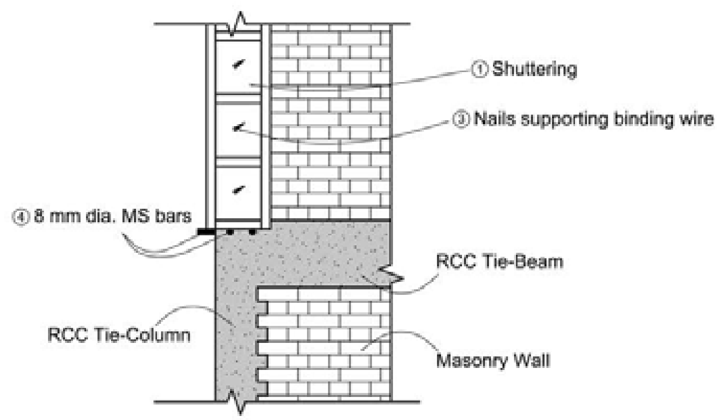
Formwork for tie-columns. The main challenge related to tie-column construction was placing and fixing the formwork. It was more difficult to erect formwork for tie-columns than for RC columns. This was because in confined masonry construction masonry walls were already built on two sides of a tie-column, hence shuttering had to be provided on the two remaining sides. This posed a challenge in the initial stage of construction. This challenge was resolved by tying the shuttering with wires across the brickwork.

Also, securing shuttering was most challenging at the corner tie-column locations, and the approach is illustrated in Figure 51.

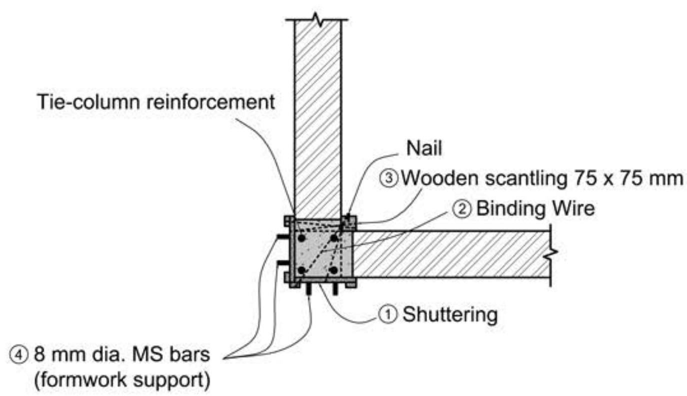
Plastic-coated ply shuttering was used for tie-column locations. The shuttering (1) was fixed with the help of binding wire (2) Nails were driven into the outer shuttering surface, and 75 mm by 75 mm wooden scantling (3) was provided on the inner side.

For ground floor shuttering, it was possible to provide the base at the bottom of shuttering. At upper floors, bottom support was available for shuttering on inner side of the building, however support was not available for shuttering plates on outer periphery at bottom. This challenge was resolved by using 8 mm MS dowel bars (4) extended from the RCC floor slab as the bottom support (see Figure 51a).

Another challenge was related to the gaps between the shuttering and the brickwork. Since only one side of brickwork is smooth and other side is rough, the shuttering didn't fix neatly to the brickwork surface; this led to slurry leakage from concrete, but the problem was resolved by plugging the gaps with Thermocol.



a) Elevation



b) Cross-Section

Figure 51. Formwork for RC tie-columns at the ground floor and upper floor levels.

4.2.4. Concrete construction

Once the shuttering was placed, it was possible to cast the tie-columns up to the specified wall height (Figure 52). To avoid segregation, concrete was compacted using needle vibrators; this was deemed appropriate due to the smaller size of tie-columns (compared to RC columns). Precaution was taken to maintain the required concrete slump so that the toothed space could be easily filled with concrete. Any spilled mortar was removed from the toothed area before the concrete was poured.

a) An interior tie-column after construction (note the construction joint at the wall mid-height)

b) Exterior tie-column at a wall intersection

Figure 52. Concrete construction for RC tie-columns.

Construction challenges:

Casting concrete in tie-columns. Vibration of concrete in RC tie-columns initially posed a challenge; this was mitigated by using a 25 mm needle vibrator.

Also, during tie-column construction it was observed that slurry was leaking through gaps between formwork and brickwork; this could lead to segregation. A gap between the formwork and the wall may be due to a rough brick surface, in which case the leakage of slurry is unavoidable. In this project a strip of soft foam material was placed between the wall and the shuttering to prevent loss of slurry.

5 Construction of Reinforced Concrete Tie-Beams and Floor and Roof Slabs

The reinforced concrete tie-beam is an integral part of each confined masonry wall. These walls must be enclosed by vertical and horizontal RC confining elements, that is, tie-columns and tie-beams. Tie-beams are constructed at floor and roof levels. In many confined masonry buildings, similar to those in this project, the floor and roof systems are RC slabs. In cast-in-place (cast-in-situ) concrete construction, the tie-beams and floor slabs are constructed simultaneously. The construction of tie-beams and slabs is described next.

5.1. Formwork

Formwork at each floor level was erected for both the tie-beams and slabs (Figure 53). The formwork was first placed inside the building, and it also served as a support for the workers laying reinforcement.

Formwork for tie-beams consisted of two wooden planks running parallel to the beam length on opposite faces. These planks were nailed to the wall. Steel wires and wooden planks were used to tie the formwork faces together (similar to the RC tie-columns). Exterior formwork for tie-beams is shown in Figure 54.

a) Setting in place interior formwork for tie-beams

b) Slab formwork was supported with steel props during and after construction

Figure 53. Formwork for tie-beams and slabs.

Construction challenges:

Formwork for tie-beams. The erection and support of formwork for tie-beams were major construction challenges. Beams were supported directly on the walls, hence there was no need to lay formwork at the bottom. Formwork was nailed to the walls on both sides. Wooden planks were used at the top of the formwork to maintain a constant beam width, and vertical formwork faces were tied with binding wires.

a) Setting in place exterior tie-beam formwork

b) Formwork for tie-beams at the ground floor level propped using wooden planks

Figure 54. Exterior formwork for tie-beams.

5.2. Reinforcement

The tie-beams and slabs were constructed monolithically, thus reinforcement for both components had to be laid before the concrete was poured. Reinforcement cages for the tie-beams consisted of four longitudinal bars and transverse reinforcement (ties) (Figure 55a). The cages were assembled on the ground and placed in position at the building site; this was very similar to construction of the RC lintel bands. Subsequently, the slab reinforcement was laid in place (Figure 55b).

a) Tie-beam reinforcement set in place

b) Construction workers laying slab reinforcement

Figure 55. Tie-beam and slab reinforcement.

It should be noted that the tie-beam-to-tie-column joints do not need to be designed for moment transfer, thus the reinforcement detailing is simpler than in RC frame construction (see Figure 56). However, proper detailing of reinforcement passing through tie-beam-to-tie-column joints is essential for minimizing damage in confined masonry buildings subjected to earthquake effects.

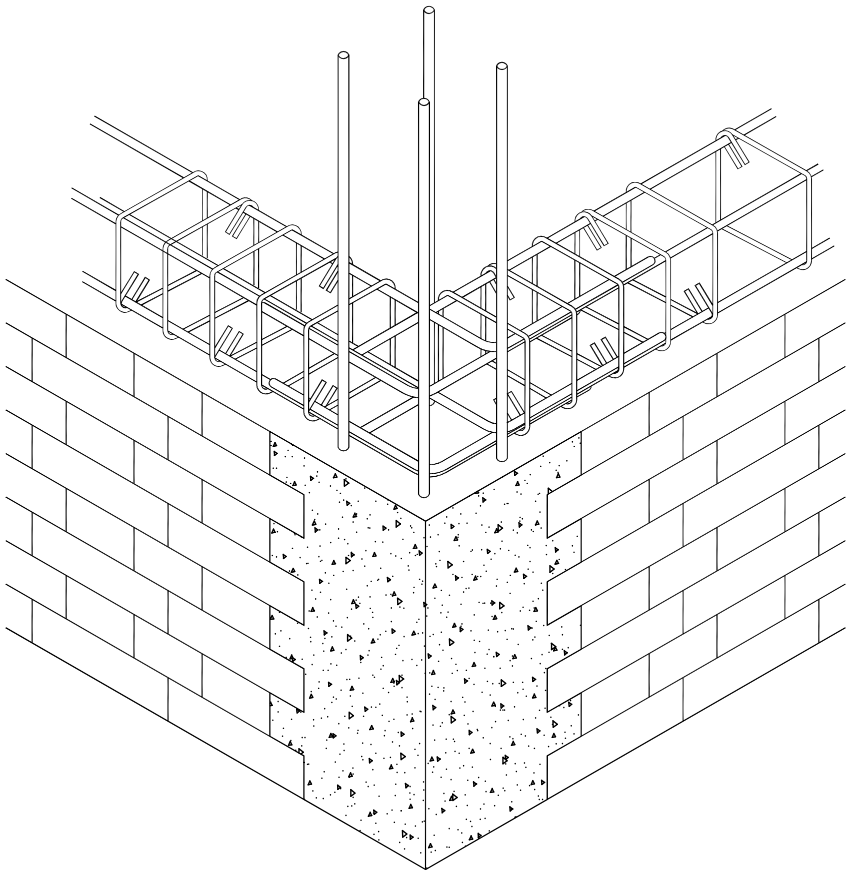


Figure 56. Tie-beam-to-tie-column joint - a recommended practice (EERI, 2011).

5.3. Concrete construction

Once the shuttering was placed, it was possible to cast concrete in the tie-beams and slab. The concrete was poured monolithically. To avoid segregation and ensure that all voids were filled, the concrete was compacted using vibrators. Finally, curing of the slab was performed for 14 days before construction of the next floor started. The concrete construction is illustrated in Figure 57.

Construction challenges:

Casting concrete in tie-beams. It was challenging to avoid bulging of the beams due to pressure from fresh concrete after the pour. To prevent bulging, the vertical formwork faces were tied at the top and at midheight.

Pouring concrete for the floor slab

Concrete compaction with a needle vibrator

Completed floor slab construction

Curing of floor slab concrete

Figure 57. Concrete construction for floor slabs and tie-beams.

6 Construction Progress and Costs

In spite of all the challenges, the construction progressed at a satisfactory pace and the quality improved over time. The construction progress and amount of materials used are summarized in Table 1. Note that the construction of structural components was completed in June 2014, and that the dates stated in the date of completion column refer to the completion of internal finishes, plumbing, and electrical systems in the buildings. Buildings under construction and the completed form are shown in Figures 58 and 59.

Table 1. Construction schedule and materials

Building type	Start of Construction	Expected Date of Completion	Concrete (m^3)	Steel (tons)	Bricks (m^3)
Faculty and Staff Housing	June 8, 2013	Jan 31, 2016	15,266	1,968	21,417
Hostels	August 1, 2013	Nov 15, 2015	13,047	1,602	15,100
Academic Buildings	August 1, 2013	Mar 31, 2016	39,000	5,210	6,500

Preliminary estimates indicate that adoption of confined masonry technology resulted in a cost saving over RC frame construction. This is based on the unit cost (Rs. per m^2), as shown in Table 2. The cost savings are due to a smaller amount of concrete and steel because of smaller member sizes in confined masonry buildings compared to RC frame buildings. For example, the required amount of steel in confined masonry buildings was 85 kg per m^3 of concrete, as compared to 130 kg of steel per m^3 of concrete for RC frame buildings. However, it should be noted that the comparison was made based on different buildings in terms of size and function (housing versus academic buildings).

Table 2. Construction costs for buildings at IIT Gandhinagar campus

Building type	Structural System	Built-up Area (m^2)	Structural Cost (Rs. Crore*)	Cost of Structure (Rs. per m^2)	Total Cost (Rs. Crore*)	Unit Cost (Rs. per m^2)
Faculty and Staff Housing	Confined Masonry	49,270	42.5	8,626	127	25,776
Hostels	Confined Masonry	35,943	32.0	8,903	79	21,979
Academic Buildings	RC Frame with Masonry Infill	45,200	71.0	15,708	192	42,478

Note:

* 1. Rs. 1 Crore = Rs. 10 Million

2. The above cost is all inclusive, i.e., building + MEP services including HVAC & passive cooling system and ELV system in the buildings and development of its appurtenent land. However, it does not include campus level development works like main roads, trunk sewer, water and drainage lines, water and sewage treatment plants, electric sub-stations and cost of electric, water and PNG supply lines to the campus.

a)

b)

Figure 58. Faculty and staff housing: a) a building under construction, and b) a completed building after plastering.

a)

b)

c)

Figure 59. Student hostels: a) a building under construction; b) a completed building, and c) a completed building after plastering.

7 Educational and Knowledge Dissemination Initiatives

Since this was the first application of confined masonry technology in a major project in India, the IITGN faculty and the CPWD engineers had several opportunities to showcase the construction process and share their experience with engineering students and academics, as well as practicing engineers and architects. A five-day Short Course on Seismic Design of Reinforced and Confined Masonry Buildings held at IITGN in February 2014 attracted 58 participants. These participants had an opportunity to visit the IITGN campus site and observe confined masonry construction (Figure 60a). The course was followed by a two-day Confined Masonry Workshop. The workshop was co-sponsored by the US-based Earthquake Engineering Research Institute (EERI) and the National Information Centre of Earthquake Engineering (NICEE) based at IIT Kanpur in India. It brought together about 20 engineers and architects from India, Mexico, USA, and Canada who discussed a path forward for confined masonry in India (Figure 60b). Following up on the workshop recommendations, a team of masonry experts from India, Mexico, and Canada started to work on developing code provisions and explanatory notes for the seismic design of engineered confined masonry buildings in India. These events were hosted by the Safety Centre at IITGN.

a) *b)*

Figure 60. Confined masonry initiatives at IITGN - site visits: a) participants of the short course, and b) participants of the confined masonry workshop.

During the period from January to April 2014, 17 IITGN civil engineering graduate students were enrolled in the course Analysis and Design of Masonry Buildings (CE613). The course was offered for the first time at IITGN and was taught by Dr. Svetlana Brzev. The students learned key concepts of structural and seismic design of reinforced and confined masonry buildings. The students also worked on a design project of a confined masonry building and made a field trip to the IITGN Palaj Campus to observe masonry construction and interact with the site engineers and contractors (Figure 61). Undergraduate students at IITGN also visited the site in March 2014. CPWD engineers and contractors should be commended for accommodating numerous site visits in spite of the busy construction schedule.

As a result of the exposure to confined masonry design and construction through coursework and site visits, few IITGN civil engineering graduate students have chosen research topics related to confined masonry for their M.Tech. theses.

a)

b)

Figure 61. IITGN civil engineering graduate students at the Palaj campus site: a) during a CPWD overview presentation, and b) at the site with CPWD engineers.

8 *Conclusions*

The adoption of confined masonry technology for this project will lead to safer buildings at lower construction costs compared to alternative options. This is a first of its kind show-case project which is hoped to popularize confined masonry in India and have a far-reaching impact on the construction industry throughout the country. CPWD is a major Government of India construction agency and this was their first project using confined masonry construction. It is expected that CPWD specifications will be modified in the future to include confined masonry. This will facilitate field applications of this technology in other projects in India.

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This publication is the first in a series describing the development of IIT Gandhinagar's campus on the bank of river Sabarmati in Gandhinagar. The campus development provided numerous opportunities for innovation and the series is meant to document these.

The focus of this first document is on the use of confined masonry for the housing. Confined masonry construction has a proven record of good seismic performance, is economical, and does not require very large engineering effort in design and construction. This publication describes the use of confined masonry construction technology for thirty-plus housing buildings (student hostels and faculty and staff apartments). It is hoped that this monograph will help sensitize and educate building professionals in India and elsewhere about the excellent features of confined masonry.

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