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APPLICATION OF CONFINED MASONRY IN A MAJOR PROJECT IN INDIA

Sudhir K. Jain[1], Dhiman Basu[1], Indrajit Ghosh[1], Durgesh C. Rai[2], Svetlana Brzev[3], and Laxmi Kant Bhargava[4]

ABSTRACT

Good seismic performance of modern confined masonry construction practiced in many countries relies on two key features, namely confinement and bond between masonry walls and reinforced concrete confining elements that enclose these walls. These two features were perceived by builders and engineers in India since the 1897 Assam earthquake. “Assam type housing” that emerged in the earthquake-affected area utilizes the concept of lateral confinement, while the 1931 Beluchistan earthquake demonstrated the importance of bond for improved seismic performance of masonry structures. Unfortunately, these lessons have been lost over time and confined masonry construction is currently not practiced in India; this is mostly due to the lack of relevant design and construction standards. However, over the last five years, several initiatives have been launched to promote confined masonry construction and revive its application in India based on its proven record of good seismic performance in India and other countries. As a result of these initiatives, the first large scale application of modern confined masonry construction in India is currently in progress. Master-plan of the permanent campus of Indian Institute of Technology Gandhinagar, a fully residential campus on 400 acres of land envisages the construction of 36 confined masonry buildings, including three- and four-story faculty and staff residences and hostels. This paper describes the campus development project, including the design process and the challenges faced during design and construction.

[1]Indian Institute of Technology Gandhinagar, Ahmedabad 382424, India
[2]Indian Institute of Technology Kanpur, Kanpur 241616, India
[3] British Columbia Institute of Technology, Burnaby, BC, Canada V5G3H2
[4] Central Public Works Department, Government of India, Ahmedabad, India

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ABSTRACT

Good seismic performance of modern confined masonry construction practiced in many countries relies on two key features, namely confinement and bond between masonry walls and reinforced concrete confining elements that enclose these walls. These two features were perceived by builders and engineers in India since the 1897 Assam earthquake. “Assam type housing” that emerged in the earthquake-affected area utilizes the concept of lateral confinement, while the 1931 Beluchistan earthquake demonstrated the importance of bond for improved seismic performance of masonry structures. Unfortunately, these lessons have been lost over time and confined masonry construction is currently not practiced in India; this is mostly due to the lack of relevant design and construction standards. However, over the last five years, several initiatives have been launched to promote confined masonry construction and revive its application in India based on its proven record of good seismic performance in India and other countries. As a result of these initiatives, the first large scale application of modern confined masonry construction in India is currently in progress. Master-plan of the permanent campus of Indian Institute of Technology Gandhinagar, a fully residential campus on 400 acres of land envisages the construction of 36 confined masonry buildings, including three- and four-story faculty and staff residences. This paper describes the campus development project, including the design process and the challenges faced during design and construction.

Introduction

In many developing countries such as India, significant number of deaths during earthquakes is caused by poor performance of unreinforced masonry (URM) buildings. Further, quite often the reinforced concrete (RC) buildings in such countries leave much to be desired in terms of design and construction quality, making them highly vulnerable to strong ground shaking. In such a scenario, confined masonry can be an effective construction technology in view of the following: a) same materials are used as are prevalent in the country, that is, concrete, masonry, and steel, and b) it only requires nominal care in design and construction and yet performs very well in earthquakes.

In recent years, authors of this paper have been actively engaged in advocating for application of confined masonry in India and other countries. A few initiatives have been taken in India, mostly related to i) strategic meetings, ii) publications, iii) research, and iv) training courses. In January 2008, National Information Centre of Earthquake Engineering (NICEE) [1] at the Indian Institute of Technology Kanpur (IITK), with support from the Earthquake Engineering Research Institute (EERI) and the World Seismic Safety Initiative (WSSI), organized an international workshop on confined masonry coordinated by Prof. Sudhir K. Jain, where 19 experts from 8 countries discussed and debated the issues related to applications and promotion of confined masonry in countries where this technology is not practiced. The

Workshop resulted in creation of Confined Masonry Network [2], which builds on experience and resources from countries in which confined masonry construction has been practiced (e.g. Blondet [3]), as discussed by Hart and Brzev [4]. Subsequently, in April 2011 Indian Institute of Technology Gandhinagar (IITGN), together with IIT Kanpur and Buildings and Materials Technology Promotion Council (BMPTC), organized an International Workshop on Confined Masonry. Around 15 invitees from Canada, USA, New Zealand, Peru, and India participated in the workshop. More recently, in February 2014 another confined masonry workshop was hosted by the Safety Centre at IIT Gandhinagar. The workshop was co-sponsored by the EERI and NICEE, and it brought together about 20 experts from India, Mexico, USA, and Canada who discussed a path forward for confined masonry in India. As a result of the workshop, a team of masonry experts from India, Mexico, and Canada is currently developing a guideline and code provisions for seismic design of engineered confined masonry buildings in India.

Several publications have been developed and published in India, mostly through NICEE, to create awareness of and promote application of confined masonry in Indian subcontinent, as discussed by Rai and Jain [5]. In 2005, Dr. S. Brzev spent several weeks at IIT Kanpur to develop a monograph "Earthquake-Resistant Confined Masonry Construction" that was published by the NICEE [6] (in English and Hindi). NICEE also published a monograph on confined masonry construction for builders authored by Tom Schacher [7]. BMTPC funded a project at IITK to popularize the use of confined masonry in India, including the development of two Earthquake Tips on confined masonry. Earthquake Tips are an extremely popular NICEE publication authored by Dr. C.V.R. Murty [8] that describe concepts of earthquake-resistant design in a simple, lucid and graphical manner. Dr.C.V.R. Murty of IIT Jodhpur has led the development of a guideline for non-engineered confined masonry construction of social housing in India that was recently published by Gujarat State Disaster Management Authority [9].

A few notable research projects have been undertaken in India since the inception of the confined masonry initiative, including a study on in-plane and out-of-plane seismic response of confined masonry walls performed by Dr. D.C. Rai and his team at the IITK ([10], [11]) and a study on seismic response of a scaled model of confined masonry building at the Central Building Research Institute, Roorkee by A. Chourasia [12]. A five-day short course on seismic design of reinforced and confined masonry buildings held at IITGN in February 2014 presented a rational approach for seismic design of engineered confined masonry buildings for the first time in India. The course was attended by about 60 academics, practicing engineers, and students from various parts of India.

Development of a fully-residential 400-acre academic campus of IITGN in the State of Gujarat, India provided an excellent opportunity for the first large-scale formal deployment of confined masonry in India. After careful consideration, it was decided to construct three-story faculty and staff housing (for 270 families) and four-story student hostels (for 1200 students) in confined masonry. The application of confined masonry in this project is expected to lead to enhanced earthquake safety and significant cost savings. This paper provides an overview of the design and implementation processes related to this project, and discusses various technical and non-technical challenges and the related solution strategies. A few issues that require appropriate solutions before confined masonry is adopted on a wide scale in India are also discussed.

Indian Seismic and Construction Scenario

India is divided into four seismic zones, namely, Zones II through V that are associated with intensity of shaking (on MSK Scale) of VI and lower, VII, VIII, IX and above [13]. Approximately 60 % of the land area of the country falls in Zone III or above, and hence, expected earthquake intensity level is VII or higher according to the MSK scale.

However, Indian construction practice is largely populated by unskilled workers, so most buildings are non-engineered. This has caused unusually large casualties in past earthquakes. For example, the September 1993 Latur, Maharashra earthquake (magnitude 6.4; maximum intensity of shaking IX) led to a death toll of 7,928. The buildings damaged were primarily made of the stone masonry and mud mortar. In January 2001, Bhuj earthquake (magnitude 7.9; maximum shaking intensity X) that struck the Kutch area of Gujarat caused huge human and economic losses: death toll was 13,805, and over 167,000 people were injured, while the estimated economic loss was approximately US$ 5 billion. Both older non-engineered masonry buildings and modern RC buildings were affected by the earthquake. Ahmedabad city (population 5.5 million), which is about 220 km away from the epicentre, experienced shaking intensity VII on MSK scale, and the maximum ground acceleration of 0.11g was recorded in the instrumented Passport Office building. Shaking experienced during the earthquake was consistent with Ahmedabad’s location in seismic zone III (expected shaking intensity of VII). Despite that, 130 RC frame buildings in Ahmedabad collapsed leading to a death toll of 805. All these buildings were "engineered", that is, professional architects and structural engineers were involved in their design and construction. Hence, the quality of construction and understanding of the seismic design philosophy might be questionable even though these buildings were constructed in the formal sector.

Clearly, inherently robust building technologies are needed to ensure good seismic performance and reduce death toll even when adequate engineering input is not involved. Confined masonry construction can be considered as one such viable alternative.

Confined Masonry Construction Technology

Structural components of a confined masonry building are (Fig. 1): i) masonry walls - transfer both lateral and gravity loads from the floor and roof slabs down to the foundations; ii) horizontal and vertical RC confining elements (tie-beams and tie-columns) - provide confinement to masonry walls and protect them from collapse, even during major earthquakes; iii) RC floor and roof slabs –distribute gravity and lateral load to the walls; iv) RC plinth band - transfers the loads from walls to the foundation system and reduces differential settlement; and v) foundation –transfers the load to the underlying soil. In a confined masonry panel, the masonry wall is constructed first leaving the toothing at either end (Fig. 2a). Vertical RC confining elements, also called tie-columns, are then cast. The entire panel height is usually constructed in two 1.2 to 1.5 m high lifts (Fig. 2b). Once the wall construction is completed up to the total story soffit level, RC tie-beams are constructed atop the walls and the concrete is cast monolithically with the floor slab. A difference in the construction sequence between confined masonry and RC frames with masonry infill walls may be noted. Unlike infill walls, confined masonry walls are loadbearing walls and carry gravity load. Vertical RC confining elements are not expected to sustain significant gravity loads; hence, these elements are smaller in size than columns in a RC frame structure. RC confining elements are effective in enhancing strength, stability and integrity of masonry walls against the in-plane and out-of-plane seismic excitation. They have a significant role in enhancing ductility and improving the overall seismic behavior of a building. Reinforcement is usually provided only in RC confining elements, although in some cases a provision of horizontal reinforcement may be required to increase shear resistance of masonry walls. Tie-beam-to-tie-column joints are not designed for moment transfer, thus reinforcement detailing is simpler than in case of RC frame construction.

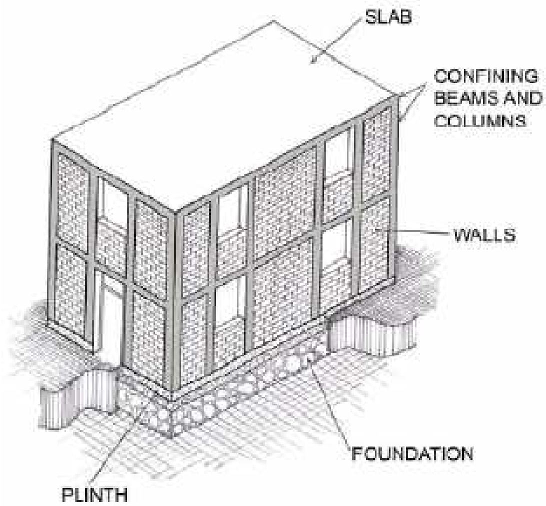

Figure 1: A typical confined masonry building [3].

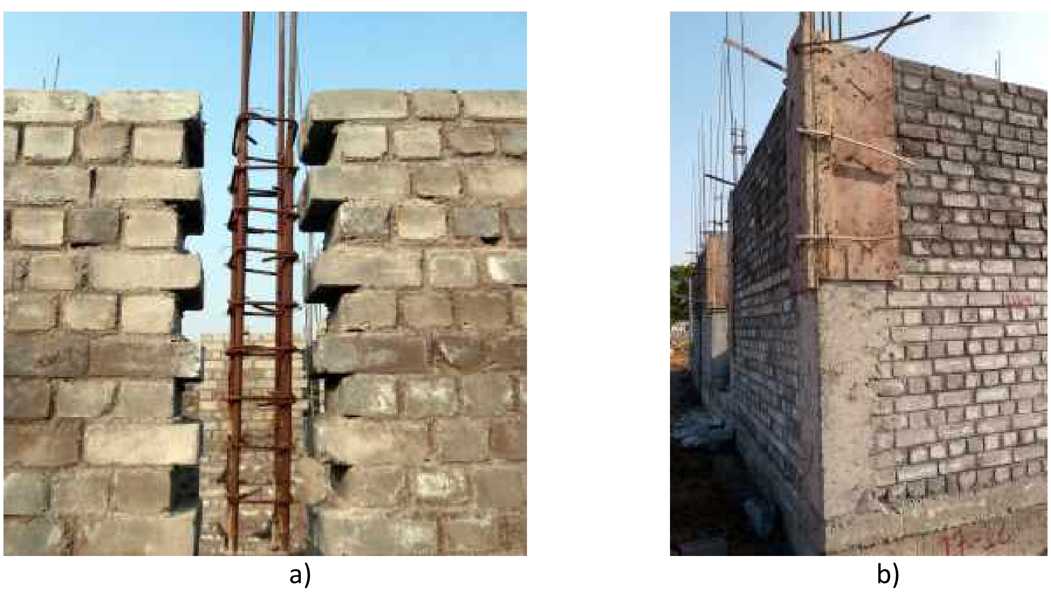

Figure 2: Construction details: a) toothing, and b) formwork for RC tie-columns.

As a result, good seismic performance can be achieved with confined masonry construction, however a satisfactory quality of construction must be ensured. Furthermore, confined masonry construction essentially combines two construction technologies, namely, masonry and RC, which are prevalent in Indian construction practice; this is expected to facilitate acceptability in Indian setting, provided that the construction workers are given training at the initial stage.

IIT Gandhinagar Campus: An Overview

Along with many other new universities, IIT Gandhinagar (IITGN) became a part of the IIT system in the academic year 2008/09. The Institute is currently housed in the premises of Vishwakarma Government Engineering College in Chandkheda, Ahmedabad. In July 2012, a piece of land at Palaj village, Gandhinagar District, measuring about 163 Hectares (403 Acres) was provided by the Government of Gujarat for setting up the IITGN permanent campus. The site is located in seismic Zone III as per the Indian seismic code [13], which implies a shaking intensity of VII (MSK Scale). For Zone III, the Indian code prescribes peak ground acceleration of 0.16g at the Maximum Considered Earthquake (MCE) level, and 0.08g at the Design Basis Earthquake (DBE) level. Therefore, design of the IITGN campus demands adequate attention from seismic viewpoint.

The Institute has retained three reputed consulting firms to carry out planning and design of student hostels, faculty and staff apartments, and academic buildings. The construction work is being executed by a project team of the Central Public Works Department (CPWD), a construction wing of the Government of India.

After Phase I construction is completed, the fully-residential new campus will house 2,400 students and associated faculty and staff. Eventually, the campus is expected to host about 6,000 students. In Phase 1A of the campus development (currently in progress), academic buildings, student hostels for 1,200 students, faculty and staff residences, and the related infrastructure has been undertaken. The construction includes about 40,000 m^2 of academic area, consisting of three- and four-story RC frame buildings to house laboratories, classrooms, and offices. There are six four-story hostel buildings with single- and double-occupancy rooms for undergraduate and graduate students (including three hostels for undergraduate male students, two hostels for graduate students, and one for female students). In addition, a three-story dining block is being constructed using RC frame system. The total hostel area under construction is about 36,000 m^2 on a land parcel of about 30,000 m^2.

To house the faculty and staff, 30 three-story buildings with 270 apartments in total are being constructed with the total construction area of about 48,000 m^2 on a land parcel of about 60,000 m^2. The apartments are of three types, with the carpet area ranging from 108 to 256 m^2.

Student hostels and faculty and staff housing were ideal candidates for the adoption of confined masonry technology, in terms of building height, small room size (compared to academic facilities), and a significant amount of walls (wall density). Preliminary estimates indicate that adoption of confined masonry technology would lead to a cost saving of 10 to 15% over alternative RC frame construction.

Design of Confined Masonry Buildings

Current Indian masonry design standard IS 1905 [14] does not contain provisions related to confined masonry construction. Therefore, the project team used EERI guidelines for design of low-rise confined masonry buildings [15] and other resources ([6], [7]), with due modifications related to site seismicity and material properties. Design of reinforced concrete conformed to the IS 456 standard requirements [16].

Material Properties

Mechanical properties of masonry materials were determined through a series of tests conducted at IIT Kanpur. Three sets of bricks of two types of units (burnt clay and fly ash) manufactured in Ahmedabad were tested to determine their mechanical properties. To determine masonry compressive strength, masonry prisms were fabricated in the laboratory using two different mortar mix proportions: i) 1:1:6 cement: lime: sand mix and ii) 1:4 cement: sand mix. Clay bricks had an average compressive strength of 5.4 MPa, while the strength of fly ash bricks ranged from 5.3 to 9.1 MPa (for the first and second set respectively). Fly ash bricks appeared to be highly absorptive; for that reason, clay bricks with low water absorption characteristics were used in foundations below the plinth level. Fly ash bricks were characterized with significantly higher water absorption than clay bricks, hence it was decided to use these bricks only for above grade masonry construction. Based on the test results of masonry assemblages, a set of recommended design values have been obtained (Table 1), which are compatible with the Allowable Stress Design Method according to IS 1905 [14], wherever applicable.

Table 1. Masonry material properties.

Masonry Type	Compressive Strength of Masonry f_m (MPa)	Basic Compressive Stress (MPa)	Elastic Modulus of Masonry (MPa)	Permissible Shear Stress (MPa)	Tensile Strength (MPa)
Clay bricks 1:1:6 cement: lime:sand mortar	3.9	0.97	$250 f_m$	Minimum of the following: a) 0.5 MPa, b) $0.1+0.35 f_d$ c) $0.125 \sqrt{f_m}$ where f_d is compressive stress due to dead loads (MPa)	0.05
Clay bricks 1:4 cement: sand mortar	3.8	0.95			
Fly ash bricks (Set#1) 1:1:6 mortar	3.0	0.76	$550 f_m$		0.07
Fly ash bricks (Set#1) 1:4 mortar	3.6	0.89			0.05
Fly ash bricks (Set#2) 1:1:6 mortar	7.6	1.83			0.07
Fly ash bricks (Set#2) 1:4 mortar	6.8	1.71			0.05

Foundations below the plinth level were constructed using conventional masonry, that is, burnt clay bricks in 1:4 cement:sand mortar with the minimum brick compressive strength of 5.0 MPa. FPS Fly Ash Lime Gypsum (FALG) bricks in 1:1:6 cement:lime:sand mortar with the specified brick compressive strength of 9.0 N/mm^2 were used for above grade masonry construction. A preliminary survey showed that FALG bricks manufactured in Gandhinagar and

Ahmedabad districts and nearby areas generally do not possess compressive strength specified for the project, unless manufactured under strict supervision and control. Furthermore, the project required a significant brick supply (about 100,000 bricks/day), which was not available at the local market within a short time frame. Therefore, plants for manufacturing FALG bricks were set up at the construction site. The bulk quantity of fly ash was available from the nearby thermal plants, and good quality lime was procured from the neighboring Rajasthan state (Hydrated Lime Class 'C 'conforming to IS 712 standard [17] in the form of a fine dry powder). Concrete grade M25 (25 MPa characteristic compressive strength) conforming to IS 456 standard [16] was used throughout the project.

Design Approach

Confined masonry is a loadbearing wall structural system, wherein gravity load is sustained by walls only and contribution of RC tie-columns in gravity load sharing was ignored. Allowable compressive stresses for masonry walls were computed considering slenderness effects and load eccentricity per IS 1905 [14].

Lateral load is resisted by masonry walls confined by vertical and horizontal RC confining elements. It was assumed that shear failure mechanism governs in the wall design. Seismic capacity of confined masonry buildings was evaluated through wall density index, which is defined as the ratio of wall area to the floor area of the building. EERI guidelines [15] recommend the minimum wall density ratio based on the Simplified Method, depending on the type of masonry units, site seismicity, soil conditions, and the building height and mass. For this project, masonry units were solid bricks, the site is located in Zone III of India, which could be classified as moderate seismicity (Peak Ground Acceleration less than 0.25g), and the soil is of compacted granular type. For these parameters, the guidelines recommend a minimum wall density of 1 and 2% for one- and two-story buildings, respectively. In line with that, minimum wall density of 1% per story was used for this project (e.g. 3 and 4 % wall density for three- and four-story buildings respectively). Only walls confined on all sides were considered for wall density calculations. Note that walls with height/length ratio of 1.5 or higher and walls with large openings were ignored in wall density calculations, hence these walls were not considered to contribute to seismic capacity of the building.

Seismic base shear force was calculated according to IS 1893 [13], and subsequently distributed up the building height. Importance factor (I) of 1.0 and the response reduction factor (R) of 2.5 were used in the design. As a reference, R factor of 1.5 is prescribed for unreinforced masonry construction, 3.0 for ordinary RC moment resisting frames, and 5.0 for special RC moment resisting frames. Average shear stresses in walls at the ground story level were calculated by dividing the base shear force by the wall cross-sectional area (same area as used for wall density calculations). Seismic forces in the walls were increased by 15% to account for amplification due to torsional effects. The resulting shear stresses were compared with the allowable shear stress reported in Table 1. It was assumed that overturning moment in a confined masonry wall panel is resisted through axial tension and compression stresses in RC tie-columns.

Design and Construction Challenges

Considering that this is the first reported application of confined masonry in India, it is no surprise that the project team faced a number of design and construction challenges and dilemmas. First of all, architectural team was not familiar with the features of confined masonry buildings in terms of layout and planning. Structural design team debated whether RC tie-columns require isolated (spread) footings similar to columns in RC frame construction, or it is adequate to start the tie-columns at the RC plinth band level (with the provision of adequate anchorage for longitudinal reinforcement). The latter alternative was pursued to expedite the construction process and minimize foundation costs. For that reason, RC plinth band (with 400 mm depth) was more robust than in conventional masonry construction practice. Another design challenge was related to areas around staircases which did not meet the wall density requirements. Therefore, these areas were treated as RC frame systems and were isolated from the adjacent confined masonry construction through expansion joints (seismic gaps). Seismic gaps were also used in a few buildings with a complex plan shape to create simple rectangular segments in order to minimize torsional effects.

Detailing of RC confining elements is critical for seismic safety of confined masonry buildings. To ensure adequate shear resistance of RC tie-columns, closely spaced ties (100 mm spacing) were provided in RC tie-columns. This is a conservative provision, since most codes and guidelines require closer tie spacing over one-quarter of the floor height, and an increased (e.g. 200 mm) spacing is prescribed for the remaining portion of a tie-column. Detailing of the joints between tie-beams and tie-columns was simpler than in RC frame construction since these joints do not need to be detailed for moment transfer. Masonry walls did not have any horizontal reinforcement, with the exception of RC lintel bands provided continuously along the wall length above openings (doors and windows). Although a provision of RC lintel band is not common in confined masonry buildings in countries where this technology has been practiced, the team decided to provide lintel bands to comply with the provisions of Indian seismic design standard IS 4326 [18] for loadbearing masonry buildings located in Zone III of India.

The team has also faced several construction challenges. The most significant challenge was related to explaining confined masonry to construction workers. It was essential to explain how is confined masonry different from RC frame construction which is widely practiced in India, and why are some construction features (e.g. toothing) critical for seismic safety. Another challenge is related to construction of RC tie-columns, specifically shuttering that needs to be placed on two sides for an interior column, or four sides for a corner column. At the initial construction phase, it was challenging to attach shuttering to the walls – unlike RC frame construction where clamps have been routinely used. However, this challenge was overcome by an approach where a mix of clamps and steel wire ties were passed through RC tie-columns. Implementation of toothing between RC tie-columns and masonry walls was also challenging in the initial stage, but in the end it was possible to achieve adequate toothing of about 50 mm in conjunction with the English bond used for masonry construction.

In spite of these challenges, the construction has progressed at a satisfactory pace and the quality has improved compared to the initial stage. As of this writing (March 2014), out of 30 housing blocks (three-story buildings), 18 blocks are at the second story level and the remaining 12 blocks are at the top story level. A typical housing block under construction is shown in Fig. 3a. Construction of hostel buildings (six four-story buildings) is at different stages: three buildings have been completed, two buildings are at the top story level, and one is at the second story level (Fig. 3b). Overall progress achieved since the start of construction (six month period) is at the 35 and 45 % mark for housing and hostels respectively (relative to the total building value).

a) b)

Figure 3: Building construction in progress: a) faculty and staff housing, and b) a hostel.

Concluding Remarks

The authors of this paper believe that adoption of confined masonry technology in this project will lead to safer buildings at lower construction costs compared to alternative options. More importantly, this is expected to be a show-case project which is hoped to popularize confined masonry in India and have a far-reaching impact on the construction industry in the country. CPWD is a major Government of India construction agency and this was their first project that uses confined masonry construction technology. It is expected that CPWD specifications will be modified to include confined masonry; this will facilitate field applications of confined masonry in other projects in India.

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