EDUCATIONAL INITIATIVES IN PROMOTING CONFINED MASONRY FOR IMPROVING EARTHQUAKE RESILIENCE IN INDIA

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Abstract

India, with a population above 1.2 billion, has nearly 60% of its land area vulnerable to earthquake shaking ranging from moderate to very severe. The performance of buildings in past earthquakes in India has been poor, with collapses contributing to thousands of fatalities. By and large, building damage in past Indian earthquakes can be attributed to the two predominant typologies, namely reinforced concrete (RC) frames and loadbearing unreinforced masonry wall buildings. Though reinforced masonry with seismic bands is prescribed by Indian seismic codes, most masonry buildings in earthquake-prone areas in India do not have any form of reinforcement. Similarly, in spite of seismic code provisions for design and detailing of RC buildings, many such buildings are either inadequately designed or constructed (or both). Confined masonry (CM), as a structural typology, has been used for decades in earthquake prone regions of the world, where it has proved its efficacy to resist earthquake shaking and can be used in India, as an alternative to unreinforced masonry and RC frame typologies. The conversation on CM started in India in 2008, with an international meeting of global practitioners and academics, experienced in the use of CM in earthquake prone regions of the world. Subsequently, research studies on the performance of CM under seismic conditions have been carried out at several Indian universities, and a draft code for seismic design of CM buildings is currently under consideration by the Bureau of Indian Standards. Indian Institute of Technology Gandhinagar (IITGN) adopted CM technology for the construction of staff and student housing for its campus, this being the first instance of large-scale use of CM in the formal sector. A number of CM-related publications were initiated by the National Information Centre of Earthquake Engineering (NICEE), including the monograph on CM for engineers and architects published in 2007, and illustrated guidebooks on CM construction for masons and builders in the informal building sector. A few worskhops and international seminars for engineers and academics have been conducted during the past few years for the dissemination of CM to a wider nationwide audience. A few short courses and seminars on the subject were conducted for engineering participants at IITGN. Architectural design precedes structural decision making in building projects, and the structural typology is chosen fairly early in the design decision making process. Recognizing this, a significantly expanded third edition of the CM monograph was published in 2018, with an entire chapter on architectural design guidelines for CM buildings and design case studies. The book was classroom-tested in 2019 in a workshop for architectural students held in IIT Kanpur, and used by the participants to undertake the design of a school building with a design brief drawn from real life projects. This paper provides an overview of the CM initiative in India, with an emphasis on the different ongoing activities in capacity building and promoting CM.

Keywords: confined masonry; earthquake-resistant design; India; engineering and architectural education; resilience

1. Introduction

Severe damage or collapse of buildings has been the main cause of fatalities in earthquakes in India and other developing countries. Human losses in Indian earthquakes have been unacceptably high. Between 1900 and 2006, more than 23,000 lives were lost due to six major earthquakes in India [1]. On January 26, 2001, magnitude 7.7 Bhuj earthquake struck the Kutch area of Gujarat and 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 approximately US$ 5 billion [2]. Both older non-engineered masonry dwellings and modern reinforced concrete (RC) apartment buildings were affected by the earthquake. Ahmedabad city (population 5.5 million), located 220 km away from the epicentre, experienced shaking intensity VII on the MSK scale resulting in the collapse of 130 RC frame buildings and a death toll of 805. In the 1993 Latur earthquake with the death toll of nearly 8000, at least one village lost 30% of its population due to the collapse of heavy roofs on people sleeping in their homes in the early hours before daybreak [3]. The most popular construction typologies in India are unreinforced load bearing masonry and moment resisting RC frames (RC), which are frequently inadequately designed and constructed. Confined masonry (CM) that uses the same materials as the unreinforced masonry and RC systems has been successfully used in many earthquake-prone areas of the world, where their performance in earthquake shaking has been good. In addition to the familiarity of the materials used, this typology does not require as much specialized care during design and construction as RC frame systems, and yet it performs well in earthquake shaking.

CM is not formally practiced in India though some informally built composite masonry and RC constructions employ some aspects of CM construction practice. Responding to this lack of awareness about CM, a number of initiatives were taken up during the past decade. This paper describes the ongoing capacity building initiatives to promote CM in India through research, education and practice.

2. The Indian Scenario

2.1 India’s earthquake hazard setting

India is located in one of the most earthquake prone regions of the world. The past two decades have seen devastating effects of earthquakes striking India with alarming regularity— Imphal 2016, Sikkim 2011, Kashmir 2005, Bhuj 2001, Chamoli 1999, Jabalpur 1997, Latur 1993, Uttarkashi 1991—causing over 20,000 deaths. The entire Himalayan belt is considered prone to earthquakes of magnitude exceeding 8.0, and in a relatively short span of about fifty five years, four such earthquakes had occurred: 1897 Shillong (M8.7), 1905 Kangra (M8.0), 1934 Bihar-Nepal (M8.3), and 1950 Assam-Tibet (M8.6) [4].

The current Seismic Zoning Map divides the country into four seismic hazard zones of II to V with no areas under “no hazard” [5]. According to the Vulnerability Atlas of India, nearly 60% of the land area of the country is subject to risk ranging from moderate damage risk to very high damage risk [6]. This corresponds to expected intensities ranging from MSK VII in moderate hazard zones to MSK IX or more in very high damage zones and implies that the entire country is subject to the earthquake hazard. The zones are associated with increasing intensity of ground shaking. Zone V covers areas with high seismic hazard which are expected to be exposed to earthquakes of intensity MSK IX and above, including parts of Jammu and Kashmir, the Himalayas, North-East India and parts of Gujarat. Overlaying the population figures on the Sesimic Zone Map of India reveals that approximately 78% of India’s 1.25 billion population, falls within the moderate to severe hazard levels. Several Indian mega-cities, including Delhi, Mumbai, and Kolkata, are located in regions of moderate to high seismic risk [7].

2.2 Building stock

In 2011 the Census of India [8] reported the total number of houses in urban India as 110.14 million and out of a total of 330 million housing units in the country overall. The building stock in India is comprised of a range of different building materials used in different combinations in buildings. The two most common typologies prevalent in India are masonry buildings and RC frame buildings. Masonry buildings may be built with burnt clay bricks or adobe blocks, stone (coursed or un-coursed) and concrete blocks, RC frame buildings have concrete columns and beams with the infill panels made up of unreinforced masonry, usually using burnt clay bricks. The quality of these materials varies widely across the country as do construction practices and workmanship. About 71 million households have houses with concrete roofs; nearly 76 million with tiled roofs (handmade and machine made clay tiles), 21 million with stone/slate roofs and another 37 million have 'Grass' thatch, etc, as the material for the roof. Thus, about 150 million households live in houses that have no roof diaphragms, are therefore vulnerable to damage and even collapse due to even moderate earthquake shaking.

The data on condition of the census houses reveals important information. The condition of houses was classified as Good/Livable/Dilapidated based on the perception and response of the occupants. According to the Census [8], 244 million houses were reported to be used solely as 'residence' or 'residence-cum-other use' (mixed use). The condition of nearly 130 million of these houses has been reported as 'Good', nearly 101 million as 'Livable' and 13 million as 'Dilapidated'. Fig.1 shows that the urban housing stock is in a better condition and is perceived to be so by the occupants as compared to the rural housing stock. With average population of 5 persons per house, 65 million people in India, by their own admission, live in houses that are dilapidated and which could be affected by moderate levels of earthquake shaking.

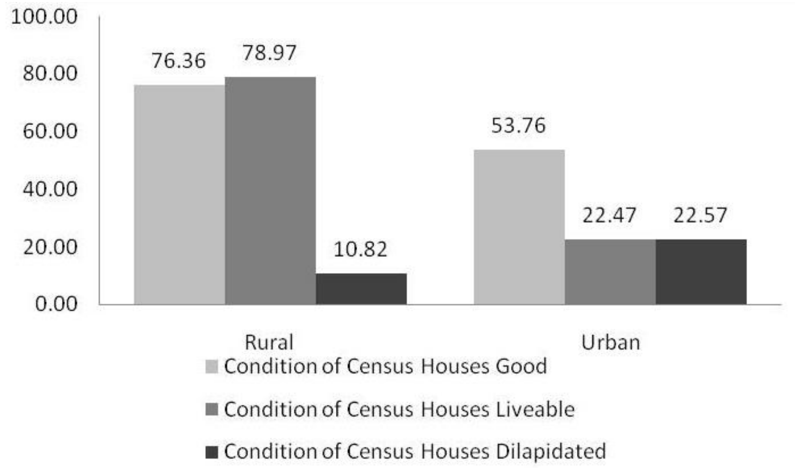

Fig. 1 – Condition of houses in rural and urban areas of India as reported by occupants [8]

2.3 Housing shortage and construction boom

India is on the brink of a massive housing boom, with a goal of construction of 30 million new housing units by 2022 [9], [10]. In 2001, about 286 million people were living in urban areas across India, the second largest urban population in the world. In 2011, the Census [8] reported that the urban population had increased to 377 million, thereby registering a growth of around 32 %. The urban areas have also seen a rise of 53.8% in the number of houses built, a reflection of the increasing demand for housing across the country and the easy access to housing loans from banks and other lending institutions, especially amongst the urban households.

3. Confined Masonry Construction Technology

Poor earthquake performance of improperly designed or detailed RC and unreinforced masonry buildings worldwide resulted in economic losses and fatalities which are well documented. This prompted a need for developing and promoting alternative building technologies. CM technology has performed extremely well in past earthquakes and is an alternative both for unreinforced masonry and RC frame construction in low- and medium-rise buildings. CM construction comprises loadbearing masonry walls enclosed by vertical RC confining elements (tie-columns) and horizontal elements (tie-beams), as illustrated in Fig. 2. In most cases, floor and roof structures are RC slabs, but it is possible to use flexible roof structures in CM buildings, which is a practice in some countries (e.g. Indonesia).

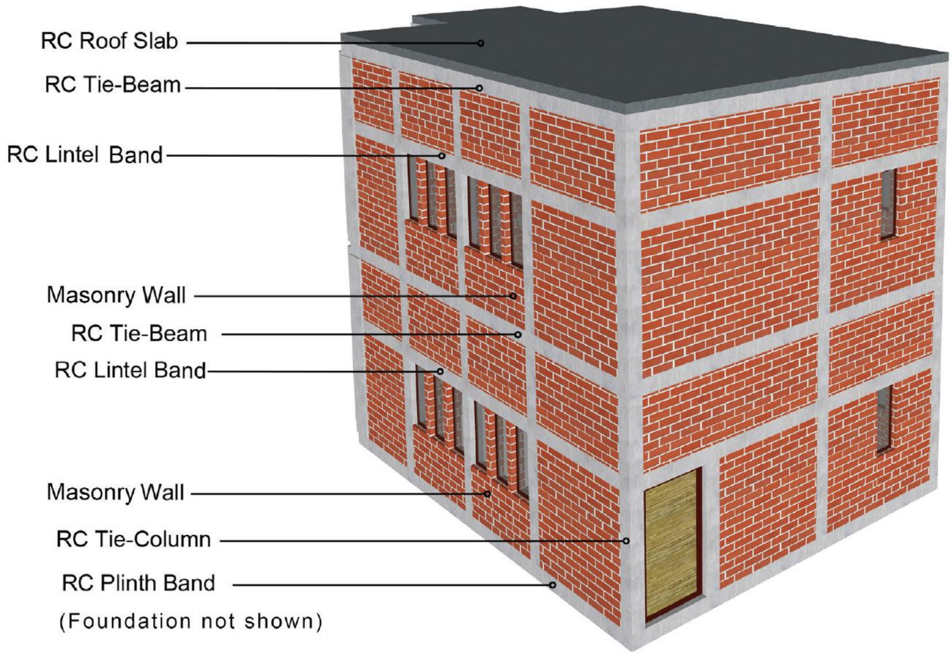

Fig. 2 – Key components of a CM building [31]

CM construction has evolved through an informal process based on its satisfactory performance in past earthquakes. The first reported use of CM construction was in the reconstruction of buildings destroyed by the 1908 Messina, Italy earthquake (M 7.2), which killed over 70,000 people. Well-built CM buildings have survived the effects of major earthquakes without collapse, and in most cases without significant damage. CM was practiced in Chile and Columbia since 1930's and in Mexico since 1940's. It is currently practiced in several countries/regions with high seismic risk, including Latin America, Mediterranean Europe, Middle East (Iran), South Asia (Indonesia) and the Far East (China).

In India, loadbearing masonry construction is widely used for housing in rural areas and suburban areas of large cities. This typology is not suitable for buildings taller than four storeys. In the absence of a viable alternative, RC is preferred and used widely for taller buildings. However, RC frame construction requires engineering inputs and proper detailing and supervision. The poor earthquake performance of buildings in India can be attributed to a lack of capacity of stakeholders in the building delivery process, a poor enforcement regime, and lack of awareness; unfortunately, the demand for safe buildings is simply not present. The municipal regulations lack teeth and it is not unusual, particularly in semi-urban and rapidly developing peri-urban areas for construction projects to be executed without applications for building permits, hence there is a lack of opportunities for enforcing building regulations. It is suggested that in the rural context, CM is a viable alternative, since there are hardly any building regulations in rural areas and housing construction is largely owner-driven. CM buildings use the same familiar materials (masonry, concrete, and steel) as RC frame buildings, and the rules for design and construction are relatively simple and easy to master by masons with nominal training, that is, without the rigour required for successful execution of RC frame construction. CM is also more forgiving of minor design and construction flaws, as well as material deficiencies, provided that the buildings have regular floor plans and meet a few simple requirements pertaining to the building configuration and wall layout.

4. Capacity Building Initiatives for Promoting CM Construction Technology in India

4.1 Workshops and meetings

In January 2008, National Information Centre of Earthquake Engineering (NICEE) [11] 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 Strategy Meet on the Global Dissemination of CM Technology coordinated by Prof. Sudhir K. Jain, where 19 experts from 8 countries discussed and debated the issues related to applications and promotion of CM in countries where this technology is not practiced. The meeting resulted in creation of the CM Network [12], which builds on experience and resources from countries in which CM construction has been practiced, such as Peru.

Subsequently, in April 2011, IIT Gandhinagar (IITGN), together with IITK and Buildings and Materials Technology Promotion Council (BMPTC), organized an International Workshop on CM. About 15 invitees from Canada, USA, New Zealand, Peru, and India participated in the workshop. In February 2014, the second international CM workshop was hosted by the Safety Centre at IITGN [13]. 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 CM in India. In 2016 and 2018 BMTPC organized seminars on Emerging Building Materials and Construction Technologies, where the authors made a presentation on CM, which generated interest among large number of practicing engineers and building contractors [14], [15]. In March 2019 IITGN hosted a two-day India-Nepal workshop on implementation of CM in these countries. More than 20 participants from India and Nepal, including leading academics, government officials, and engineers, participated in the workshop.

4.2. Training of engineering professionals

A five-day short course on seismic design of reinforced masonry and CM buildings was held at IITGN in February 2014, and it attracted 60 engineers and academics from throughout India. It was the first training program in India where a rational approach for modelling and design of engineered CM buildings was presented and illustrated through design examples [14]. In April 2019, a full-day confined masonry seminar was held at IITGN, which attracted more than 130 participants, mostly practicing engineers from various parts of India. The seminar presented current state of research, development, and design applications of CM in India. The speakers included masonry experts from India, Mexico, and Canada. Other events that involved training of engineering professionals related to CM have been conducted by faculty members from IITK and IIT Patna.

4.3 Training of engineering students

Design of masonry structures has been a part of the curriculum at a few universities in India, such as IITK, IIT Roorkee, IIT Guwahati, IIT Madras, etc. Besides field applications of CM construction with its campus, IITGN is probably the first Indian university which offers a full-semester graduate course focused on analysis and design of CM buildings (CE613). The course was first offered in 2014, and to date it was attended by more than 50 civil engineering students. The course curriculum covers masonry materials, structural design of CM walls for gravity and lateral loading, structural analysis of CM buildings, and seismic design aspects. The course has a strong project component, and the students were assigned to carry out design of a CM building located on campus. The students had multiple opportunities to observe first-hand ongoing CM construction on the campus. A short course on structural design of CM buildings (15-hour duration) was conducted at IITGN in May 2017 for more than 25 students from IITGN and other universities from the Ahmedabad area. Undergraduate students at IITGN have a mandatory masonry design course (CE307) in which they are exposed to the fundamental concepts of CM design and construction.

4.4 Training of architectural students

In 2008, NICEE started a week-long Workshop on Earthquake Resistant Architectural Practices for third year students of architecture from colleges all over India which has been held at IITK [31]. The workshop mimics a typical architectural design studio wherein a few lectures in the first one and a half days are followed by intense hands-on studio sessions where architecture and structural engineering faculty guide the students in the preparation of their design projects. The projects are evaluated by an independent jury panel comprising architects and structural engineers, and prizes are awarded to the first three rank holders. Since its inception in 2008, more than 700 students from about 55 colleges from India and Nepal have been trained. Around 34 faculty and professionals have volunteered to run this workshop as resource faculty and jury members, year after year.

In 2019, the focus of the workshop was CM, and the main technical resource was the CM monograph [31]. The participants were required to design a CM school building in Bhuj, Gujarat, located in Seismic Zone V of India. The participants were divided into 30 two-member teams where each team member was from a different institute, and were asked to develop a design proposal which should be rational in functional, structural and aesthetic terms. While the participants were encouraged to adopt innovative design approaches, the objective of this design exercise was to evaluate their understanding of earthquake-resistant architecture and application of the same in a design project through the application of CM.

CEPT University in Ahmedabad offers undergraduate and graduate programs for architectural and civil engineering students and also organizes short courses on the topics of interest. A short course on the planning and design of CM buildings was offered in May 2016 and May 2019, with more than 50 students from CEPT and other Indian universities. The focus of the 2-week, 80-hour course was to expose students to fundamentals of earthquake-resistant design of CM buildings, both from architectural and engineering perspectives. The course was delivered through lectures, practice assignments, quizzes, and a design project engaging multi-disciplinary teams of architectural and engineering students. In the 2016 offering of the course the students were assigned design of a school building in Nepal, while in 2019 they were asked to design a housing complex at the IITGN campus.

5. Publications

Several publications have been developed and published in India, mostly through NICEE, to create awareness and promote application of CM within Indian subcontinent [26]. In 2005, Dr. S. Brzev spent several weeks at IITK to develop a monograph "Earthquake-Resistant Confined Masonry Construction" that was published by the NICEE [27]. More than 3000 copies of the monograph (1st and 2nd edition) were circulated in English and Hindi over the 10-year period. In 2018 the third edition of this publication was released under sponsorship by NICEE, BMTPC, and IITGN [31], as discussed in the following paragraph. NICEE also published a monograph on CM construction for builders authored by Swiss architect Tom Schacher [28]. BMTPC funded a project at IITK to popularize the use of CM in India, and also sponsored the development of Earthquake Tips, an extremely popular NICEE publication which describes concepts of earthquake-resistant design in a simple, lucid and graphical manner [29]. Two out of 32 earthquake tips explain the concepts of CM. Dr. Murty also led the development of a guideline for non-engineered CM construction of social housing in India that was sponsored and published by Gujarat State Disaster Management Authority [30].

The third edition of CM monograph, co-authored by Dr. S. Brzev and Dr. K. Mitra, has been significantly updated to provide a comprehensive overview of global advancements in CM in terms of construction practices, design, and research studies [31]. The book contains nine chapters. Chapter 1 provides a brief overview of the seismic history of the Indian subcontinent vis-a-vis its seismotectonic profile and explains how buildings resist earthquakes. Chapters 2 to 4 discuss the main features of CM construction and how CM is different from RC frame construction. Factors that influence the performance of CM structures are introduced to assist the reader in understanding the important issues. Chapter 5 documents the performance of CM buildings in past earthquakes worldwide. Chapter 6 presents architectural design guidelines that highlight the key considerations for conceptual design of CM buildings and provide several recommendations for ensuring their seismic adequacy. Chapter 7 illustrates a simple method for checking whether a layout designed by the architect is suitable from the seismic design perspective. Though seismic design is primarily the responsibility of a structural engineer, the architect can perform a preliminary check to confirm that the proposed wall layout is likely to be satisfactory. Two design case studies presented in this chapter illustrate how to perform these checks. Since CM involves both masonry and RC construction, the importance of good practices related to the field execution of these two construction technologies cannot be overemphasized. Chapter 8 contains key recommendations related to the construction of CM buildings, showcasing model construction specifications for CM buildings.

The publication provides a basic background related to seismic design and planning of CM buildings for architects and structural engineers. Architects play an important role in defining the overall shape, size and dimensions of a building. They may also determine the locations and lengths of CM wall panels in both plan directions. Structural engineers are responsible for providing numerical proof of structural safety and need to work closely with architects to ensure that the design meets both structural and architectural requirements.

Architectural planning and conceptual design depend on the building function, occupant needs, climate, and other factors. This iterative process starts with the selection of the construction site, followed by the selection of building-plan shape and dimensions. For CM buildings, it is important to find an optimal wall layout, which has critical implications on the seismic safety of a building. Architects need to consider seismic safety when developing layout, length, and thickness for CM walls in the building. Since CM walls are loadbearing walls, size and location of openings need to be carefully determined to avoid negative implications on seismic safety. Simple guidelines are provided for the conceptual architectural planning and design of CM buildings, grouped under the four sections of Building Configuration, Wall Layout, Confining Elements and Openings.

Building configuration is a case in point. Configuration, both with regard to plan and elevation, is arguably the key issue that ensures the satisfactory performance of a building during an earthquake. Experience from past earthquakes has shown that buildings with regular plan and elevation perform better than irregular buildings. However, to accommodate different activities in a residential building, and to admit natural light and ventilation to the interior spaces, it is not always possible to have perfectly regular plan shape with minimum projections, which is desirable. The publication provides guidance regarding irregular plan shapes, in which a seismic gap can be provided to form regular blocks (Fig. 3).

The publication also presents a simple preliminary design tool based on the Wall Index (wall density) approach which can be used by architects and engineers to perform a preliminary check of the wall layout from the seismic design perspective. The Wall Index, *WI*, is the ratio of the total cross-sectional area of walls aligned in one principal direction of the building plan and the floor plan area. The designer needs to determine the *WI* for each direction of the building plan and compare it with the required value, which depends on the type of masonry units, site seismicity, soil conditions, and the building height and mass. Two design case studies are also presented to explain the application of *WI* concept for seismic safety check of CM buildings. One of the design case studies presents a comparison of RC frame and CM design solution for the same building (Fig. 4).

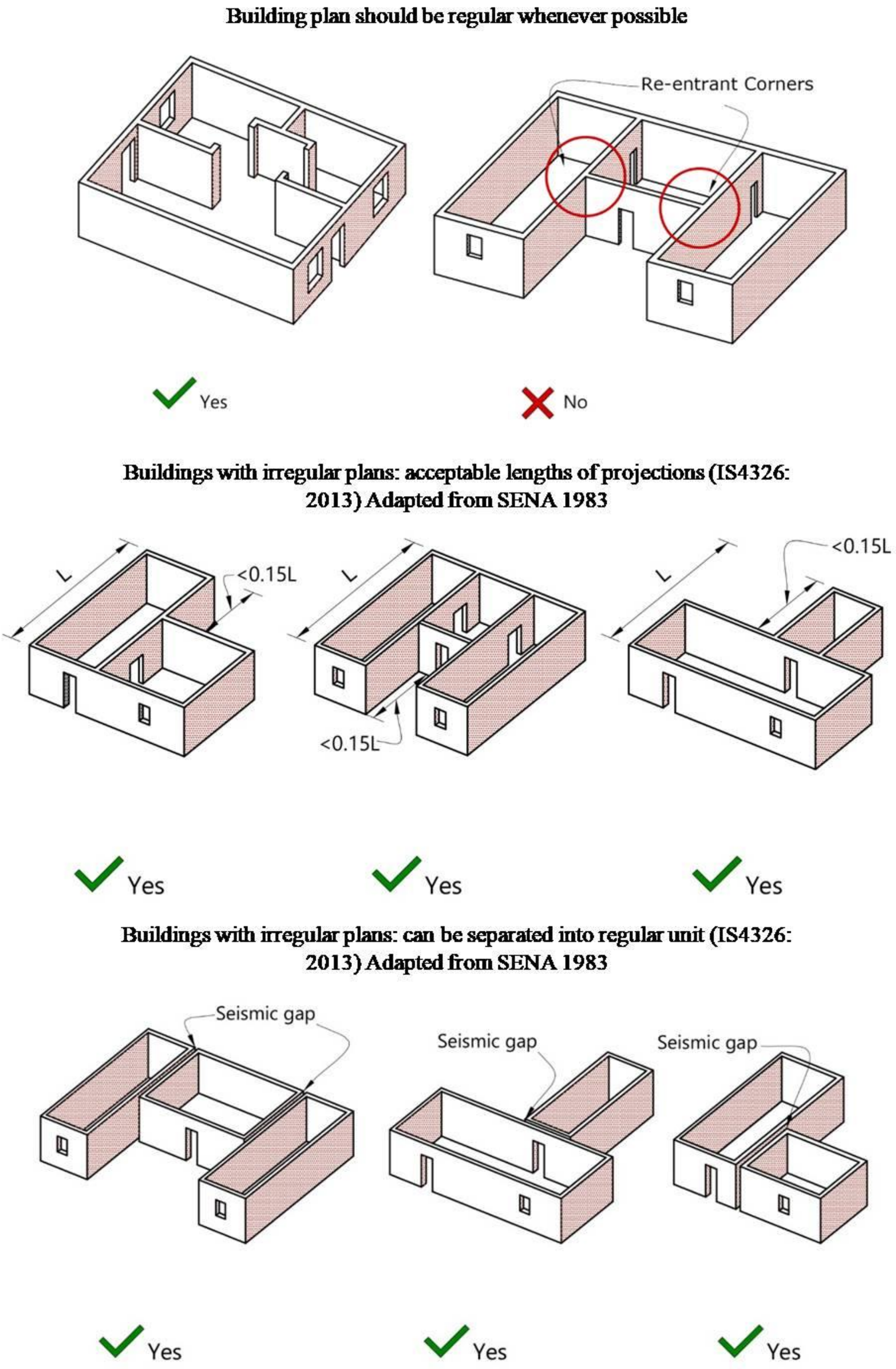

Fig. 3 - Building configuration: regular and irregular plans [31]

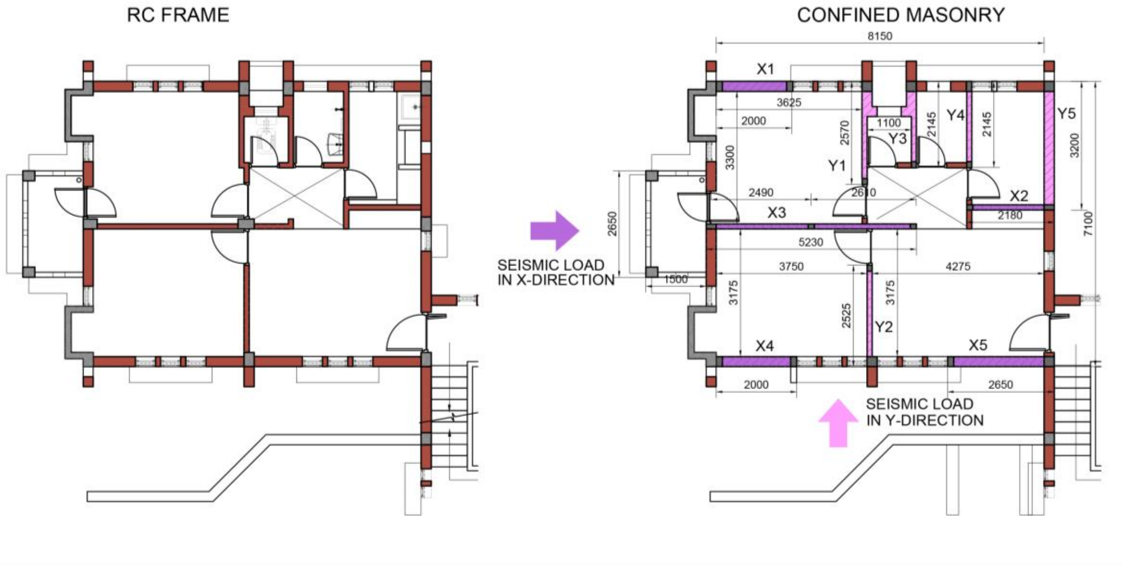

Fig. 4 – Design case study: a comparison of RC frame and CM design solution for the same apartment building [31]

5. Research Studies

A few notable research studies have been undertaken in India since the inception of the CM initiative. A comprehensive experimental study on in-plane and out-of-plane seismic response of CM walls was performed by Dr. D.C. Rai and his students at IITK [16], [17]. CM walls performed much better than masonry infill RC frames and could maintain structural integrity for in-plane drifts as large as 1.75%. A study on seismic response of a scaled model of CM building was performed at the Central Building Research Institute, Roorkee [18], [19].

A few analytical research studies on simulating seismic behaviour of CM structures have been performed in India. Equivalent Frame Model (EFM), also known as Wide Column Model, is a well-known macro-modelling approach, which has been used for analysis of RC shear walls for almost 50 years. Application of EFM for linear and nonlinear seismic analysis of CM buildings was studied at IITGN [20]. As an alternative to EFM, Strut-and-Tie Model (STM) can be also used for modelling CM buildings. STM is an integrated analysis and design approach in which a structure or a structural member subjected to applied static loads is idealized as a truss-like system. IITGN researchers proposed guidelines for developing STMs for seismic design of CM walls with and without wall openings, and showed that the strut layout depends on the applied loading configuration, wall geometry, as well as the size and location of openings [21]. A truss-based modelling approach for CM structures subjected to increasing monotonic or cyclic lateral loading is termed Equivalent Truss Model (ETM). Development and application of ETM for seismic analysis of CM buildings has also been explored at IITGN and IIT Kanpur [22], [23]. It has been shown that with a few simplifying assumptions, STMs may provide good predictions for the in-plane strength and lateral displacements of CM walls within 10% and 15% error respectively when compared to the experimental results [22].

Simplified equations for estimating the strength and stiffness of CM walls can be handy tool for design engineers. Using the simple measure of the degree of confinement provided by RC confining elements, the proposed method for sub-paneled masonry walls can be used for reliable prediction of in-plane strength both for solid CM walls and walls with openings [24].

Findings of Indian research studies and experience related to CM construction practice from other countries have served as the basis for a draft Indian code for seismic design of CM buildings, which is currently under consideration by the BIS [25].

6. The Way Forward

CM has proven its efficacy in earthquake-prone regions of the world. It is a technically and economically viable alternative to unreinforced masonry and RC frame typologies. In India, the CM initiative started in 2008 with a global meet of professionals, academics and practitioners, and received an impetus a few years later, with the design and construction of permanent campus of the IIT Gandhinagar, which featured the first large-scale application of engineered CM construction in the country and served as a living lab for CM construction accessible to hundreds of visitors. In total, thirty 3-storey housing blocks and twelve 4-storey student hostels have been constructed using CM technology. Director's residence, a single-storey bungalow, has also been constructed using CM technology. IITGN community featured this pioneering application of CM technology in an informative publication for architects and engineers [33]. An exterior view of the housing complex at IITGN campus is shown in Fig. 5.

Fig. 5 – Completed CM housing at the IIT Gandhinagar campus, Palaj, Gujarat [33]

At present, there are several publications on CM targetted at different audiences in India, including professionals in the design and construction disciplines, and also architects and students of architecture. However, CM is not a part of the standard curriculum in civil engineering and architecture programs in India. Though around 70% of the construction in India uses masonry as the preferred typology, this receives very little coverage in the course curricula. At least, in architecture colleges, students in the early stages of coursework have some exposure to masonry as they design low-rise structures with small plan footprints. Inclusion of CM in the design curriculum of colleges and polytechnics offering courses in civil engineering and architecture is a necessary first step in bringing CM to the palette of options available. At the same time, experimental research on CM needs to be stepped up in the technical institutions and research laboratories, and initiative has to be taken for application of the research outcomes in the field. Engineering design code for CM is needed for its widespread application. This, alongwith development and dissemination of design resources for engineers and architects, and awareness building regarding CM and its advantages as an alternative to RC frames with masonry infills for low- to medium-rise buildings, are some key actionables for popularizing CM among design professionals in India. An awareness of the safety and cost effectiveness of CM among the general public, can bring CM within the ambit of options for owner-driven housing popular in rural areas, which are outside the purview of any building regulatory systems.

7. Acknowledgements

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