World Housing Encyclopedia

A Resource on Construction in Earthquake Regions

an initiative of
Earthquake Engineering Research Institue (EERI) and
International Association for Earthquake Engineering (IAEE)

HOUSING REPORT

Reinforced concrete frame building with masonry infill walls designed for gravity loads

Report#	19
Last Updated	
Country	India
Author(s)	Kishor S. Jaiswal, Ravi Sinha, Alok Goyal,
Reviewers	Craig D. Comartin,

Important

This encyclopedia contains information contributed by various earthquake engineering professionals around the world. All opinions, findings, conclusions & recommendations expressed herein are those of the various participants, and do not necessarily reflect the views of the Earthquake Engineering Research Institute, the International

Association for Earthquake Engineering, the Engineering Information Foundation, John A, Martin & Associates, Inc. or the participant's organizations.

General Information

Building Type:	Reinforced concrete frame building with masonry infill walls designed for gravity loads
Country:	India
Author(s):	Kishor S. Jaiswal Ravi Sinha Alok Goyal
Last Updated:	
Regions Where Found:	Buildings of this construction type can be found in entire India. This type of housing construction is commonly found in both rural and urban areas. These constructions were found only in urban areas in the past. However, now due to rapid urbanization of the society and easy availability of necessary raw materials, these structures are also constructed in semi-rural and large rural communities. However, the quality of design and construction remains variable and highly questionable in all locations.
Summary:	The construction of reinforced concrete buildings with brick masonry infill walls has been a very common practice in urban India for the last 25 years. Most of this construction has been designed for gravity loads only, in violation of the Code of Indian Standards for earthquake-resistant design. These buildings performed very poorly during the Bhuj earthquake of January 2001 and several thousand buildings collapsed. The collapse was not limited to the epicentral region. The seismic vulnerability of this construction is clearly demonstrated by the collapse of about 75 RCC frame buildings and damage to several thousand others in and around Ahmedabad, which is over 250 km from the epicenter.
Length of time practiced:	25-60 years
Still Practiced:	Yes
In practice as of:	
Building Occupancy:	Residential, 20-49 units

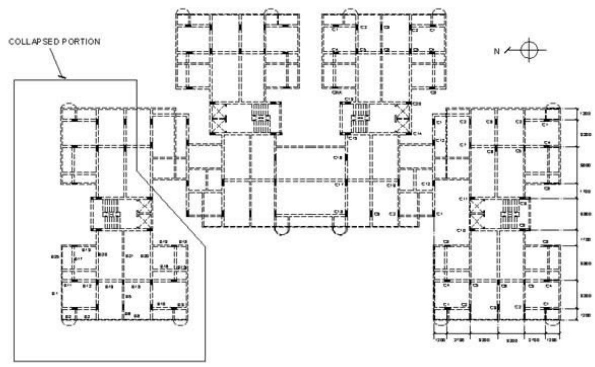
Typical number of stories:	5-10
Terrain-Flat:	Typically
Terrain-Sloped:	Typically
Comments:	This construction practice has become very common in urban areas during the last 25 years. In most situations, multi-story apart

Features

Plan Shape	Irregular plan shape
Additional comments on plan shape	Building configurations may be very irregular for multi-story apartments. The irregularity provides space for controlling lighting and ventilation and suits architectural requirements. However, this also results in irregular geometry of lateral load resisting elements which may result in additional torsional stresses during earthquakes.
Typical plan length (meters)	12
Typical plan width (meters)	7
Typical story height (meters)	3.2
Type of Structural System	Structural Concrete: Moment Resisting Frame: Designed for gravity loads only, with URM infill walls
Additional comments on structural system	The vertical load-resisting system is reinforced concrete moment resisting frame. The vertical load bearing system also consists of the same beam-column framing system which transfers lateral loads. The foundation may consist of spread footing or pile foundation depending on the local soil conditions. The lateral load-resisting system is reinforced concrete moment resisting frame. The lateral load resisting system consists of reinforced concrete beam-column frame system. The foundation system may consist of footings or piles depending on the soil conditions. In most urban areas, the ground floor is used for parking and consists of bare-frame while the tenements on higher floors have masonry infill walls. The walls make significant contribution to the lateral load-resisting elements on higher floors. This variation in the stiffness of lateral load resisting system results in the formation of "soft storey" on the ground floor.

	Additional difficulty is posed due to non-uniformity of the framing system due to which the load transfer path is not direct. This may results in the development of torsion and concentrated shear in the structure, which is not considered in gravity load-based design.
Gravity load-bearing & lateral load-resisting systems	
Typical wall densities in direction 1	4-5%
Typical wall densities in direction 2	5-10%
Additional comments on typical wall densities	For typical buildings, density of masonry infill wall varies between 5 to 7% in each direction.
Wall Openings	These buildings have normal openings for apartments. Since openings are created in partition walls, these openings do not have a significant bearing on the structural performance. Typical door sizes are 1.2 m # 2.1 m and window sizes are 0.9 m # 1.2 m.
Is it typical for buildings of this type to have common walls with adjacent buildings?	No
Modifications of buildings	Typical modification found in case of multistory building is in the form of alteration of position of interior walls. Additional storeys are added on many old one or two storey buildings without considering the load-carrying capacity or behaviour under earthquake loading. Open balconeys are also often enclosed in RCC buildings to increase size of rooms or to provide additional rooms.
Type of Foundation	Shallow Foundation: Reinforced concrete isolated footingDeep Foundation: Reinforced concrete skin friction piles
Additional comments on foundation	
Type of Floor System	Other floor system
Additional comments on floor system	Structural concrete: cast-in-place and precast solid slabs The RCC floor and roof slabs are considered rigid for analysis and design purposes.
Type of Roof System	Roof system, other

Additional comments on roof system	Structural concrete: cast-in-place and precast solid slabs The RCC floor and roof slabs are considered rigid for analysis and design purposes.
Additional comments section 2	When separated from adjacent buildings, the typical distance from a neighboring building is 5 meters.



Plan of a Typical 10-story Building at Ahmedabad

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
Wall/Frame	Burnt Clay	3.5-5 MPa (100 x 230 x 75)
Foundations	Concrete	15-20 MPa 1:2:4 to 1:1.5:3
Floors	Concrete	15-20 MPa 1:2:4 to 1:1.5:3
Roof	Concrete	15-20 MPa 1:2:4 to 1:1.5:3
Other		

Design Process

Who is involved with the design process?	EngineerArchitect
Roles of those involved in the design process	The architects are typically responsible for all aspects of the building project. The structural engineer is usually employed by the architect rather than the owner. The contractor is directly appointed by the owner. The level of interaction between the architect, structural engineer and the

	contractor/builder is often found inadequate.
Expertise of those involved in the design process	The architects are formally trained and licensed by their professional board. The structural engineers and contractors do not require any licensing. As a result, their expertise may be very uneven. In several situations, the building damage can be directly attributed to the lack of competence of the structural engineer or the contractor. In recent times, the city control rules and professional practices bills are under revision to remove this lacuna.

Construction Process

Who typically builds this construction type?	Contractor
Roles of those involved in the building process	In most constructions, the builder is a developer and constructs these buildings for sale in the market. In some situations, the buildings are designed and constructed by a consortium of apartment owners who get together from the project formulation stage itself.
Expertise of those involved in building process	
Construction process and phasing	Most building design responsibilities lie with the architect. The structural engineer typically works for the architect rather than the building owner. The architect is also responsible for all statuary clearances from the city officials. Due to the prevalent system, the structural engineer and the contractor/builder is typically not responsible for his work. The construction of this type of housing takes place in a single phase. Typically, the building is originally designed for its final constructed size.
Construction issues	

Building Codes and Standards

Is this construction type address by codes/standards?	Yes
	Several codes and standards address different aspects of this building design and construction. Some of the most widely referred codes include: (1) IS 456-2000: Code of practice for plain and reinforced concrete, (2) IS 1893-1984: Criteria for

Applicable codes or standards	earthquake resistant design of structures, (3) IS 13920-1993: Ductile detailing of reinforced concrete structures subjected to seismic forces # code of practice. IS 456 was last revised in 2000.IS 1893 is currently under revision and is expected to be issued soon. For Materials, there are many IS codes available depending upon type of construction material used.
Process for building code enforcement	Most building design responsibilities lie with the architect. The structural engineer typically works for the architect rather than the building owner. The architect is also responsible for all statuary clearances from the city officials. Due to the prevalent system, the structural engineer and the contractor/builder is not directly responsible for his work. Since most city bye-laws require compliance with the relevant codes, the architect is responsible for liaisoning with the city officers for all relevant permissions and sanctions and for issuing certification of code compliance. In some urban areas, the Structural Engineering also needs to give a code-compliance certificated. However, this certificate is based on design only and does not cover the construction quality issues.

Building Permits and Development Control Rules

Are building permits required?	Yes
Is this typically informal construction?	No
Is this construction typically authorized as per development control rules?	Yes
Additional comments on building permits and development control rules	

Building Maintenance and Condition

	The main problems associated with this construction type are as follows: 1. Since the buildings are designed for gravity loads only, they have very poor lateral load carrying capacity. 2. The building geometry is typically irregular leading to development of torsional forces at floor level. 3. Poor quality of concrete makes the structure

Typical problems associated with this type of construction	vulnerable to brittle failure. 4. Poor reinforcement detailing results in low ductility and leads to catastrophic collapse of these buildings. 5. Open ground floor for parking results in the development of soft story that can easily collapse due to lack of earthquake-resistant design. 6. Lack of plinth beams results in differential movement at the foundation level and introduces large moments in the columns. This also contributes to the sudden collapse of these buildings at the soft story level.
Who typically maintains buildings of this type?	Owner(s)
Additional comments on maintenance and building condition	

Construction Economics

Unit construction cost	Typical cost of construction may range from Rs. 5000 - 7500 per sq m (US$ 100 - 150 per sq m).
Labor requirements	Number of effort days required to complete the construction.
Additional comments section 3	

Perspective View Showing Key Structural Load-Bearing Elements of a Damaged Building

Photograph Illustrating Building Under Construction with Improper Reinforcement Detailing Practice

A Close up View of Building Under Construction with Improper Reinforcement Detailing of Beam-Column Joint

Beam-Column Junction with Congestion of Reinforcement Illustrating Improper Construction Practice

Socio-Economic Issues

Patterns of occupancy	These houses typically have multiple dwellings with different families living in different apartments/floors. Each floor typically has between two to four apartments, while larger number of apartments are also found in buildings for The total number of occupants in each building can go to several hundred during the nights. Building up to 5 stories generally have 8 to 20 housing units. Higher buildings may have much larger number of tenements depending on the number of stories.
Number of inhabitants in a typical building of this construction type during	10-20

the day	
Number of inhabitants in a typical building of this construction type during the evening/night	>20
Additional comments on number of inhabitants	
Economic level of inhabitants	Middle-income classHigh-income class (rich)
Additional comments on economic level of inhabitants	Ratio of housing unit price to annual income: 5:1 or worse
Typical Source of Financing	Owner financedPersonal savingsInformal network: friends or relativesCommercial banks/mortgagesGovernment-owned housing
Additional comments on financing	
Type of Ownership	RentOwn outrightOwn with debt (mortgage or other)Units owned individually (condominium)
Additional comments on ownership	
Is earthquake insurance for this construction type typically available?	No
What does earthquake insurance typically cover/cost	
Are premium discounts or higher coverages available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features?	No
Additional comments on premium discounts	
Additional comments section 4	

Earthquakes

Past Earthquakes in the country which affected buildings of this type

Year	Earthquake Epicenter
1967	Koyna
1993	Killari
1997	Jabalpur
2001	Bhuj

Past Earthquakes

Damage patterns observed in past earthquakes for this construction type	Building construction of this type (without any seismic features) suffered significant damage during Koyna (1967) and Killari (1993) earthquakes. Some damage was also observed during Jabalpur (1997) earthquake. The main damage patterns consisted of: - Shear cracks in walls, mainly starting from corners of openings. - Vertical cracks at wall corners - Partial out of plane collapse of walls due to concatenation of cracks. - Partial caving-in of roofs due to collapse of supporting walls. - Shifting of roof from wall due to torsional motion of roof slab. This type of construction was also severely affected by the 2001 Bhuj earthquake (M 7.6). In the epicentral region, several buildings of this type suffered total collapse of the walls resulting in depth and injury to large number of people. The overall performance was dependent on the type of roof system: buildings with lightweight roof suffered relatively less damage while buildings with RCC roofs suffered much greater damage. (Source: IIT Powai 2001) Importance and effectiveness of seismic provisions, in particular RC lintel and roof bands (bond beams) was confirmed both in the 1993 Killari earthquake and in the 2001 Bhuj earthquake. Buildings with seismic provisions performed substantially better and did not suffer collapse, whereas similar construction without any seismic provisions was severely affected by the earthquake.
Additional comments on earthquake damage patterns	

Structural and Architectural Features for Seismic Resistance

The main reference publication used in developing the statements used in this table is FEMA 310 “Handbook for the Seismic Evaluation of Buildings-A Pre-standard”, Federal Emergency Management Agency, Washington, D.C., 1998.

The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; For precast concrete wall structures: less than 3/4 of the length of a perimeter wall.

Structural/Architectural Feature	Statement	Seismic Resistance
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to transfer inertial forces from the building to the foundation.	TRUE
Building Configuration-Vertical	The building is regular with regards to the elevation. (Specify in 5.4.1)	FALSE
Building Configuration-Horizontal	The building is regular with regards to the plan. (Specify in 5.4.2)	FALSE
Roof Construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity, i.e. shape and form, during an earthquake of intensity expected in this area.	TRUE
Floor Construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.	TRUE
Foundation Performance	There is no evidence of excessive foundation movement (e.g.	TRUE

	settlement) that would affect the integrity or performance of the structure in an earthquake.	
Wall and Frame Structures-Redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	TRUE
Wall Proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls); Less than 13 (unreinforced masonry walls);	FALSE
Foundation-Wall Connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	TRUE
Wall-Roof Connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps.	FALSE
Wall Openings		FALSE
Quality of Building Materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	FALSE
Quality of Workmanship	Quality of workmanship (based on visual inspection of a few typical buildings) is considered to be good (per local construction standards).	FALSE
Maintenance	Buildings of this type are generally well	FALSE

maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber).

Building Irregularities

Additional comments on structural and architectural features for seismic resistance	
Vertical irregularities typically found in this construction type	Torsion eccentricity
Horizontal irregularities typically found in this construction type	Soft/weak story
Seismic deficiency in walls	Unreinforced masonry infill panels often dislodge from RC frame during out of plane vibration because of poor connection with frame members. Frequent crushing of masonry infill also results due to low strength of bricks and mortar. In plane stiffness of masonry wall is under-utilized due to lack of adequate connections in some cases.
Earthquake-resilient features in walls	High in-plane stiffness provides additional lateral load carrying capacity for RCC frames. Many multistory buildings has escaped from complete collapse in recent Bhuj earthquake due to presence of infilled masonry walls at ground floors.
Seismic deficiency in frames	Beams and columns are not connected rigidly to provide moment-resistant frame action. Most joints exhibit weak column-strong beam behaviour. All longitudinal reinforcement are often spliced at the same section resulting in stress concentration in concrete.
Earthquake-resilient features in frame	The frames do not have significant earthquake-resistant features. In most buildings, the in-fill walls contributed to shear-wall action and enhanced the seismic resistance of these buildings.
Seismic deficiency in roof and floors	Slabs are generally 100 to 120 mm thick and cast-in-place with beams and column. Same grade concrete is generally used for all structural elements.
Earthquake resilient features in roof and	High in-plane stiffness of RCC slabs enable transfer of earthquake forces to the different frames, and

floors	improve earthquake-resistance of the buildings.
Seismic deficiency in foundation	Spread foots are not properly connected to each other with plinth beams. When these beams exist, they are not designed to resist moments due to earthquake forces.
Earthquake-resilient features in foundation	The foundations do not have significant earthquake-resistant features.

Seismic Vulnerability Rating

For information about how seismic vulnerability ratings were selected see the Seismic Vulnerability Guidelines

	High vulnerability		**Medium vulnerability**		**Low vulnerability**	
	A	B	C	D	E	F
Seismic vulnerability class		|-	o		-|	

Severe Damage and Plastic Hinging of Ground-Floor Column Due to Improper Confinement of Concrete and Lapping of Large Number of Longitudinal Bars

Damage to Ground Floor Columns Due to Inadequate Lateral Confinement of Reinforcement Bars

Failure of Column Below the Beam-Column Joint Due to Short Column Effect

View of the Intact Portion of an Apartment Building (2001 Bhuj Earthquake)

View of Shear Damage of an Elevator Core (2001 Bhuj Earthquake)

Pancake Collapse of a Multistory Building Due to Weak Column-Strong Beam Design (2001 Bhuj Earthquake)

A Photograph Illustrating Typical Earthquake Damage

Failure of Lower Two Stories of the Right Wing of an Apartment Building With Soft Story. Note that the Left Wing Without Soft Story is Apparently Undamaged (2001 Bhuj Earthquake).

Underutilization of Shear Capacity of Elevator Core Due to Improper Diaphragm Action of Slabs Resulted in Failure of an Apartment Building (2001 Bhuj Earthquake)

Shear Failure of Column Just Below the Beam-Column Junction Due to Poor Construction Material and Insufficient Lateral Reinforcement (2001 Bhuj Earthquake)

Retrofit Information

Description of Seismic Strengthening Provisions

Structural Deficiency	Seismic Strengthening
Unreinforced masonry infill panels often dislodge from RC frame during out of plane vibration because of poor connection with frame members. Frequent crushing of masonry infill also results due to low strength of bricks and mortar. In plane stiffness of masonry wall is under-utilized due to lack of adequate connection in some cases.	Damaged walls can be repaired by filling cracks using epoxy or cement slurry of adequate strength. Walls with significant cracks may require local replacement of crushed masonry blocks before grouting. Walls that have suffered very significant damage including partial or full collapse may need to be replaced with new wall.
Beams and Columns are not connected rigidly to provide moment-resistant action. Most joints exhibit weak column strong beam behaviour. All longitudinal reinforcement are often spliced at the same section resulting in stress concentration in concrete.	The cracks in the beams or columns are grouted with cement slurry of adequate strength and design cover is ensured while jacketing of the existing beams and columns. Reinforcement as per the newly designed sections can be placed and proper bond between existing and new construction is maintained. Extent of corrosion to existing reinforcement is properly measured as per the procedures and suitable measures can be taken to avoid the further rusting of the reinforcement.
Slabs are generally 100 to 120 mm thick and cast-in-place with beams and column. Same grade concrete is generally used for all structural elements.	Cast-in-situ slabs are usually adequate stiff to provide diaphragm action. No special retrofitting scheme is required for slabs.
Spread foots are not properly connected to each other with plinth beams. When these beams exist, they are not adequately designed for moment resistance.	Columns may be jacketed up to foundation level. Where required, the footings may also be jacketed to increase their bearing capacity. Plinth beams may also be constructed or strengthened when relative settlement of different parts of foundation is expected.

	New Construction: Neither designed nor constructed per the current seismic design and construction codes. -Proper design and construction per code provisions can be ensured. Strong beam-weak column design of RCC joints - Adequate shear strength of columns to prevent this mode of failure can be ensured by rigorously following the provisions of ductile detailing of RCC members. Poor

Additional comments on seismic strengthening provisions	maintenance and consequent deterioration in strength - Adequate strength including consideration of ageing during design phase. Proper maintenance during the life of structure. No geotechnical investigation and improper foundation system - Detailed geotechnical investigations where necessary to consider the influence of local soil conditions on earthquake loading and member forces. Non-ductile behavior of beams and columns - Detailing as per relevant IS codes for ductile detailing of RCC members. Inadequate depth of foundation - Design of foundations per code provisions with due considerations to local soil conditions.
Has seismic strengthening described in the above table been performed?	Only high rise buildings or buildings rendering important services are seismically strengthened as per the standard practice.
Was the work done as a mitigation effort on an undamaged building or as a repair following earthquake damages?	Very few buildings of this type are attended in terms of either repair or mitigation efforts. Repairs to such construction facility is found to be primarily of non-engineered type.
Was the construction inspected in the same manner as new construction?	No
Who performed the construction: a contractor or owner/user? Was an architect or engineer involved?	Owner has spent for the seismic strengthening of existing building structure by assigning job directly to private contractor through engineer or through the architect.
What has been the performance of retrofitted buildings of this type in subsequent earthquakes?	Data not available.
Additional comments section 6	

Illustration of Improper Seismic Strengthening Practice

Seismic Strengthening of Columns by Jacketing from Top of Footing - Correct Technique (2001 Bhuj Earthquake)

Seismic Strengthening of Columns by Jacketing from Floor Level - Improper Technique (2001Bhuj Earthquake)

Termination of Column Jacket Steel at Beam Soffit Level Resulting in No Increase in Moment Capacity of Column (2001 Bhuj Earthquake)

References

IS 456 : 2000 Indian Standard Code of Practice for Plain and Reinforced Concrete (Fourth revision), Bureau of Indian Standard, New Delhi.

IS 13920 : 1993 Indian Standard Code of Practice for Ductility Detailing of Reinforced Concrete Structures Subjected to Seismic Forces, Bureau of Indian Standard, New Delhi.

IS 1893 : 1984 Indian Standard Criteria for Earthquake Resistant Design of Structures (Fourth Revision), Bureau of Indian Standard, New Delhi.

IS 4326 : 1993 Indian Standard Code of Practice for Earthquake Resistant Design Construction of Buildings (Second Revision), Bureau of Indian Standard, New Delhi.

IS 875 : 1987 Indian Standard Code of Practice for Design Loads for building Structures, Bureau of Indian Standard, New Delhi.

Authors

Name	Title	Affiliation	Location	Email
Kishor S. Jaiswal	Research Student	IIT Bombay	Civil Engineering Department, Indian Institute of Technology, Powai Mumbai	rskishor@civil.iitb.ac.in
Ravi Sinha	Associate Professor	IIT Bombay	Civil Engineering Department, Indian Institute of Technology, Powai Mumbai	rsinha@civil.iitb.ac.in
Alok Goyal	Professor	IIT Bombay	Civil Engineering Department, Indian Institute of Technology, Powai Mumbai	agoyal@civil.iitb.ac.in

Reviewers

Name	Title	Affiliation	Location	Email
Craig D. Comartin	President	C.D. Comartin Associates	Stockton CA 95207-1705, USA	ccomartin@comartin.net