World Housing Encyclopedia

*an Encyclopedia of Housing Construction in
Seismically Active Areas of the World*

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

Report #	19
Report Date	06-05-2002
Country	INDIA
Housing Type	RC Moment Frame Building
Housing Sub-Type	RC Moment Frame Building : Designed for gravity loads only, with URM infills
Author(s)	Kishor S. Jaiswal, Ravi Sinha, Alok Goyal
Reviewer(s)	Craig D. Comartin

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.

1. General Information

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.

This construction type has been in practice for less than 50 years.

Currently, this type of construction is being built. This construction practice has become very common in urban areas during the last 25 years. In most situations, multi-story apartment blocks are constructed wherein each apartment is sold to individual owners. Such buildings are usually occupied by the upper-middle and middle class people in the cities. In major metropolitan areas, such apartments are also owned by rich people. Even in earthquake-prone areas of India, traditional structural design based on gravity load continues to be practiced and most RC frame constructions are not designed for lateral loads. Almost 10% of all urban constructions in India consist of RC frame structures of which those complying with seismic requirements are negligible in number.

Figure 1: Typical Building

Figure 2: Perspective Drawing Showing Key Load-Bearing Elements

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat, sloped and hilly terrain. They do not share common walls with adjacent buildings. When separated from adjacent buildings, the typical distance from a neighboring building is 5 meters.

2.2 Building Configuration

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. 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 X 2.1 m and window sizes are 0.9 m X 1.2 m.

2.3 Functional Planning

The main function of this building typology is multi-family housing. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. Building up to three to four stories are provided with only a central staircase. Higher buildings are required to have both elevators and at least one staircase acting as fire escape. In residential buildings, a single staircase is typically provided while commercial RCC high-rise buildings may have multiple staircases.

2.4 Modification to Building

Typical modification found in case of multistory building is in the form of alteration of position of interior walls. Additional stories are added on many old one or two storey buildings without considering the load-carrying capacity or behavior under earthquake loading. Open balconies are also often enclosed in RCC buildings to increase size of rooms or to provide additional rooms.

Figure 3: Plan of a Typical 10-story Building at Ahmedabad

3. Structural Details

3.1 Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	Most appropriate type
Masonry	Stone Masonry Walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	
		2	Dressed stone masonry (in lime/cement mortar)	
	Adobe/ Earthen Walls	3	Mud walls	
		4	Mud walls with horizontal wood elements	
		5	Adobe block walls	
		6	Rammed earth/Pise construction	
	Unreinforced masonry walls	7	Brick masonry in mud/lime mortar	
		8	Brick masonry in mud/lime mortar with vertical posts	
		9	Brick masonry in lime/cement mortar	
		10	Concrete block masonry in cement mortar	
	Confined masonry	11	Clay brick/tile masonry, with wooden posts and beams	
		12	Clay brick masonry, with concrete posts/tie columns and beams	
		13	Concrete blocks, tie columns and beams	

	Reinforced masonry	14	Stone masonry in cement mortar	
		15	Clay brick masonry in cement mortar	
		16	Concrete block masonry in cement mortar	
Structural concrete	Moment resisting frame	17	Flat slab structure	
		18	Designed for gravity loads only, with URM infill walls	
		19	Designed for seismic effects, with URM infill walls	
		20	Designed for seismic effects, with structural infill walls	
		21	Dual system – Frame with shear wall	
	Structural wall	22	Moment frame with in-situ shear walls	
		23	Moment frame with precast shear walls	
	Precast concrete	24	Moment frame	
		25	Prestressed moment frame with shear walls	
		26	Large panel precast walls	
		27	Shear wall structure with walls cast-in-situ	
		28	Shear wall structure with precast wall panel structure	
Steel	Moment-resisting frame	29	With brick masonry partitions	
		30	With cast in-situ concrete walls	
		31	With lightweight partitions	
	Braced frame	32	Concentric connections in all panels	
		33	Eccentric connections in a few panels	
	Structural wall	34	Bolted plate	
		35	Welded plate	
Timber	Load-bearing timber frame	36	Thatch	
		37	Walls with bamboo/reed mesh and post (Wattle and Daub)	
		38	Masonry with horizontal beams/planks at intermediate levels	
		39	Post and beam frame (no special connections)	
		40	Wood frame (with special connections)	
		41	Stud-wall frame with plywood/gypsum board sheathing	
		42	Wooden panel walls	
Other	Seismic protection systems	43	Building protected with base-isolation systems	
		44	Building protected with seismic dampers	
	Hybrid systems	45	other (described below)	

3.2 Gravity Load-Resisting 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.

3.3 Lateral Load-Resisting System

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.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 12 and 12 meters, and widths between 17 and 17 meters. The building has 5 to 10 storey(s). The typical span of the roofing/flooring system is 5 meters. Typical Plan Dimensions: Depending upon number of individual units of housing, plan dimensions varies in a great deal. Typical dimensions of plan are 12 m X 17 m for buildings with two apartments per floor. Typical Number of Stories: Buildings up to four stories high do not require elevators and are commonly found in towns and cities. In major metropolitan areas, higher structures with elevators are constructed due to the high land cost. In metropolitan areas, RCC buildings with seven or more floors are common. Typical Story Height: Story height varies between 2.8 m to 3.2 m depending upon plan dimensions and type of housing constructions. Typical Span: Span between columns of RC frame typically varies from 4.0 m to 6.5 m. The typical storey height in such buildings is 3.2 meters. The typical structural wall density is none. For typical buildings, density of masonry infill wall varies between 5 to 7% in each direction.

3.5 Floor and Roof System

Material	Description of floor/roof system	Most appropriate floor	Most appropriate roof
Masonry	Vaulted		
	Composite system of concrete joists and masonry panels		
Structural concrete	Solid slabs (cast-in-place)		
	Waffle slabs (cast-in-place)		
	Flat slabs (cast-in-place)		
	Precast joist system		
	Hollow core slab (precast)		
	Solid slabs (precast)		
	Beams and planks (precast) with concrete topping (cast-in-situ)		
	Slabs (post-tensioned)		
Steel	Composite steel deck with concrete slab (cast-in-situ)		
Timber	Rammed earth with ballast and concrete or plaster finishing		
	Wood planks or beams with ballast and concrete or plaster finishing		
	Thatched roof supported on wood purlins		
	Wood shingle roof		
	Wood planks or beams that support clay tiles		
	Wood planks or beams supporting natural stones slates		
	Wood planks or beams that support slate, metal, asbestos-cement or plastic corrugated sheets or tiles		
	Wood plank, plywood or manufactured wood panels on joists supported by beams or walls		
Other	Described below		

The RCC floor and roof slabs are considered rigid for analysis and design purposes.

3.6 Foundation

Type	Description	Most appropriate type
Shallow foundation	Wall or column embedded in soil, without footing	
	Rubble stone, fieldstone isolated footing	
	Rubble stone, fieldstone strip footing	
	Reinforced-concrete isolated footing	
	Reinforced-concrete strip footing	
	Mat foundation	
	No foundation	
Deep foundation	Reinforced-concrete bearing piles	
	Reinforced-concrete skin friction piles	
	Steel bearing piles	
	Steel skin friction piles	
	Wood piles	
	Cast-in-place concrete piers	
	Caissons	
Other	Described below	

It consists of reinforced concrete skin-friction piles.

Figure 4: Critical Structural Details

Figure 5: An Illustration of Key Seismic Features and/or Deficiencies

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 10-20 housing unit(s). 20 units in each building. 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.

The number of inhabitants in a building during the day or business hours is 11-20. The number of inhabitants during the evening and night is more than 20.

4.2 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.

4.3 Economic Level of Inhabitants

Income class	Most appropriate type
a) very low-income class (very poor)	
b) low-income class (poor)	
c) middle-income class	
d) high-income class (rich)	

Ratio of housing unit price to annual income	Most appropriate type
5:1 or worse	
4:1	
3:1	
1:1 or better	

What is a typical source of financing for buildings of this type?	Most appropriate type
Owner financed	
Personal savings	
Informal network: friends and relatives	
Small lending institutions / micro-finance institutions	
Commercial banks/mortgages	
Employers	
Investment pools	
Government-owned housing	
Combination (explain below)	
other (explain below)	

In each housing unit, there are 1 bathroom(s) without toilet(s), 1 toilet(s) only and 1 bathroom(s) including toilet(s).

Apartment buildings are having attached lavatories to each housing units. There is no common facility of latrines and bathrooms are provided. .

4.4 Ownership

The type of ownership or occupancy is renting, outright ownership , ownership with debt (mortgage or other) and individual ownership.

Type of ownership or occupancy?	Most appropriate type

Renting	
outright ownership	
Ownership with debt (mortgage or other)	
Individual ownership	
Ownership by a group or pool of persons	
Long-term lease	
other (explain below)	

5. Seismic Vulnerability

5.1 Structural and Architectural Features

Structural/ Architectural Feature	Statement	Most appropriate type		
		True	False	N/A
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.			
Building Configuration	The building is regular with regards to both the plan and the elevation.			
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.			
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.			
Foundation performance	There is no evidence of excessive foundation movement (e.g. 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.			
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);			
Foundation-wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.			
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps			
Wall openings	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.			
Quality of building materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).			

Quality of workmanship	Quality of workmanship (based on visual inspection of few typical buildings) is considered to be good (per local construction standards).			
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber)			
Other				

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	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 underutilized due to lack of adequate connections in some cases.	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.	Typical shear cracks were observed for unreinforced masonry infill walls in recent Bhuj earthquake. Separation of infill wall from the RC frame was also observed. This was mainly due to lack of adequate connection with RC frames.
Frame (columns, beams)	Beams and columns are not connected rigidly to provide moment-resistant frame action. Most joints exhibit weak column-strong beam behavior. All longitudinal reinforcement are often spliced at the same section resulting in stress concentration in concrete.	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	Strong beam-weak column behavior was a leading cause of collapse of these buildings in Bhuj earthquake of 2001. Shear cracking and plastic hinging in columns just below the beam-column junction was widely observed.
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.	High in-plane stiffness of RCC slabs enable transfer of earthquake forces to the different frames, and improve earthquake-resistance of the buildings.	Failure of the slabs independent of the supporting frame has not been observed in this construction type. Typically, slab damage is caused due to damage in the supporting frame members.
Foundations	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.	The foundations do not have significant earthquake-resistant features.	Buildings with isolated footing and lacking proper plinth beams performed very poorly due to the increase in effective length of ground floor columns.

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is *C: MEDIUM VULNERABILITY (i.e., moderate seismic performance)*, the lower bound (i.e., the worst possible) is B: MEDIUM-HIGH VULNERABILITY (i.e., poor seismic performance), and the upper bound (i.e., the best possible) is *E: LOW VULNERABILITY (i.e., very good seismic performance)*.

Vulnerability	high	medium-high	medium	medium-low	low	very low
	very poor	poor	moderate	good	very good	excellent
Vulnerability Class	A	B	C	D	E	F

5.4 History of Past Earthquakes

Date	Epicenter, region	Magnitude	Max. Intensity
1967	Koyna	6.7	VIII (MMI)
1993	Killari	6.4	VIII (MMI)
		6.1	

1997	Jabalpur		VII (MMI)
2001	Bhuj	7.6	X (MMI)

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 (see Figure 5A) and in the 2001 Bhuj earthquake (Figure 6J). 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.

Figure 6A: A Photograph Illustrating Typical Earthquake Damage

Figure 6B: Improper Reinforcement Detailing of Beam-Column Joint

Figure 6C: Severe Damage and Plastic Hinging of Ground-Floor Column Due to Improper Confinement of Concrete and Lapping of Large Number of Longitudinal Bars

Figure 6D: Beam-Column Junction with Congestion of Reinforcement Illustrating Improper Construction Practice

Figure 6E: Damage to Ground Floor Columns Due to Inadequate Lateral Confinement of Reinforcement Bars

Figure 6F: Failure of Column Below the Beam-Column Joint Due to Short Column Effect

Figure 6G: View of the Intact Portion of an Apartment Building (2001 Bhuj Earthquake)

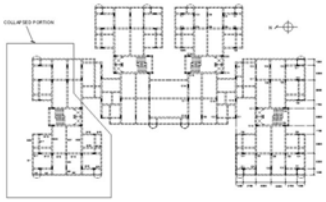

Figure 6K: View of Shear Damage of an Elevator Core (2001 Bhuj Earthquake)

Figure 6L: Pancake Collapse of a Multistory Building Due to Weak Column-Strong Beam Design (2001 Bhuj Earthquake)

Figure 6A: A Photograph Illustrating Typical Earthquake Damage

Figure 6H: 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)

Figure 6I: Underutilization of Shear Capacity of Elevator Core Due to Improper Diaphragm Action of Slabs Resulted in Failure of an Apartment Building (2001 Bhuj Earthquake)

Figure 6J: Shear Failure of Column Just Below the Beam-Column Junction Due to Poor Construction Material and Insufficient Lateral Reinforcement (2001 Bhuj Earthquake)

6. Construction

6.1 Building Materials

Structural element	**Building material**	**Characteristic strength**	**Mix proportions/dimensions**	**Comments**
Walls	Burnt Clay	3.5-5 MPa		
Foundation	Concrete	15-20 MPa	1:2:4 to 1:1.5:3	
Frames (beams & columns)				
Roof and floor(s)	Concrete	15-20 MPa	1:2:4 to 1:1.5:3	

6.2 Builder

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.

6.3 Construction Process, Problems 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.

6.4 Design and Construction Expertise

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. 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.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. Title of the code or standard: 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 earthquake resistant design of structures, (3) IS 13920-1993: Ductile detailing of reinforced concrete structures subjected to seismic forces - code of practice. Year the first code/standard addressing this type of construction issued: 1953 National building code, material codes and seismic codes/standards: For Materials, there are many IS codes available depending upon type of construction material used. When was the most recent code/standard addressing this construction type issued? IS 456 was last revised in 2000.IS 1893 is currently under revision and is expected to be issued soon.

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.

6.6 Building Permits and Development Control Rules

This type of construction is an engineered, and authorized as per development control rules. Building permits are required to build this housing type.

6.7 Building Maintenance

Typically, the building of this housing type is maintained by Owner(s).

6.8 Construction Economics

Typical cost of construction may range from Rs. 5000 - 7500 per m² (US$ 100 - 150 per m²). Number of effort days required to complete the construction.

7. Insurance

Earthquake insurance for this construction type is typically unavailable. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is unavailable.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	**Description of Seismic Strengthening provisions used**
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 underutilized 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 behavior. 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.

Strengthening of New Construction :

Seismic Deficiency	**Description of Seismic Strengthening provisions used**
Neither designed nor constructed as per the current seismic design and construction codes.	Proper design and construction as per the codal provisions can be ensured.
Inadequate depth of foundation	Design of foundations as per the codal provisions with due considerations to local soil conditions.
Non-ductile behavior of beams and columns	Detailing as per relevant IS codes for ductile detailing of RCC members.
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.
Poor maintenance and consequent deterioration in strength	Adequate strength including consideration of ageing during design phase. Proper maintenance during the life of structure.
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.

8.2 Seismic Strengthening Adopted

Has seismic strengthening described in the above table been performed in design and construction practice, and if so, to what extent?
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 repair following an earthquake?
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.

8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?
No.

Who performed the construction seismic retrofit measures: 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 was the performance of retrofitted buildings of this type in subsequent earthquakes?
Data not available.

Figure 7A: Illustration of Seismic Strengthening Techniques

Figure 7B: Seismic Strengthening of Columns by Jacketing from Top of Footing - Correct Technique (2001 Bhuj Earthquake)

Figure 7C: Seismic Strengthening of Columns by Jacketing from Floor Level - Improper Technique (2001 Bhuj Earthquake)

Figure 7D: Termination of Column Jacket Steel at Beam Soffit Level Resulting in No Increase in Moment Capacity of Column (2001 Bhuj Earthquake)

Reference(s)

1. IS 456 : 2000 Indian Standard Code of Practice for Plain and Reinforced Concrete (Fourth Revision)
   Bureau of Indian Standards, New Delhi 2000
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Author(s)

1. Kishor S. Jaiswal
Research Student, Indian Institute of Technology Powai
Civil Engineering Dept., Mumbai 400 076, INDIA
Email:rskishor@civil.iitb.ac.in

2. Ravi Sinha
Professor, Civil Engineering Department, Indian Institute of Technology Bombay
Civil Engineering Department, Indian Institute of Technology Bombay, Mumbai 400 076, INDIA
Email:rsinha@civil.iitb.ac.in FAX: (91-22) 2572-3480, 2576-7302

3. Alok Goyal
Professor, Civil Engineering Department, Indian Institute of Technology Bombay
Civil Engineering Department, Indian Institute of Technology Bombay, Mumbai 400 076, INDIA
Email:agoyal@civil.iitb.ac.in FAX: (91-22) 2572 3480

Reviewer(s)

1. Craig D. Comartin
President
, C.D. Comartin Associates
Stockton CA 95207-1705, USA
Email:ccomartin@comartin.net FAX: (209) 472-7294

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