



World Housing Encyclopedia Report

Country: India

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

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1 General Information

1.1 Country

India

1.3 Housing Type

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

1.4 Summary

The construction of reinforced concrete buildings with brick masonry infill walls is a very common practice in urban India for the last 25 years. Such construction is found throughout urban areas of the country. Most such construction is designed for gravity loads only in violation of the Indian Standards Code for earthquake-resistant design. These buildings performed very poorly during the Bhuj earthquake of January 2001 in which several thousand such buildings collapsed. The collapse was not limited to the epicentral region. About 75 RCC frame buildings collapsed and several thousand others were damaged in and around Ahmedabad, which is over 250 km from the epicenter, clearly demonstrating the seismic vulnerability of this construction.



Figure 1: Typical Building

1.5 Typical Period of Practice for Buildings of This Construction Type

How long has this construction been practiced	
< 25 years	
< 50 years	X
< 75 years	
< 100 years	
< 200 years	
> 200 years	

Is this construction still being practiced?	Yes	No
	X	

Additional Comments: 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.

1.6 Region(s) Where Used

Reinforced concrete construction is widely found in Indian cities.

1.7 Urban vs. Rural Construction

Where is this construction commonly found?	
In urban areas	
In rural areas	
In suburban areas	
Both in rural and urban areas	X

Additional Comments: 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.

2 Architectural Features

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

2.2 Siting

	Yes	No
Is this type of construction typically found on flat terrain?	X	
Is this type of construction typically found on sloped terrain? (hilly areas)	X	
Is it typical for buildings of this type to have common walls with adjacent buildings?		X

The typical separation distance between buildings is 5 meters

2.3 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.

2.4 Building Function

What is the main function for buildings of this type?	
Single family house	
Multiple housing units	X
Mixed use (commercial ground floor, residential above)	
Other (explain below)	

2.5 Means of Escape

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.

2.6 Modification of Buildings

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 2: Perspective Drawing Showing Key Load-Bearing Elements

3 Socio-Economic Issues

3.1 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.

3.2 Number of Housing Units in a Building

20 units in each building.

Additional Comments: 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.

3.3 Average Number of Inhabitants in a Building

How many inhabitants reside in a typical building of this construction type?	During the day / business hours	During the evening / night
< 5		
5 to 10		
10-20	X	
> 20		X
Other		

3.4 Number of Bathrooms or Latrines per Housing Unit

Number of Bathrooms: 1

Number of Latrines: 1

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

3.5 Economic Level of Inhabitants

Economic Status		House Price/Annual Income (Ratio)
Very poor		/
Poor		/
Middle Class	X	5/1
Rich	X	10/1

3.6 Typical Sources of Financing

What is the typical source of financing for buildings of this type?	
Owner Financed	X
Personal Savings	X
Informal Network: friends and relatives	X
Small lending institutions/microfinance institutions	
Commercial banks / mortgages	X
Investment pools	
Combination (explain)	
Government-owned housing	X
Other	

3.7 Ownership

Type of Ownership/Occupancy	
Rent	X
Own outright	X
Own with Debt (mortgage or other)	X
Units owned individually (condominium)	X
Owned by group or pool	
Long-term lease	
Other	

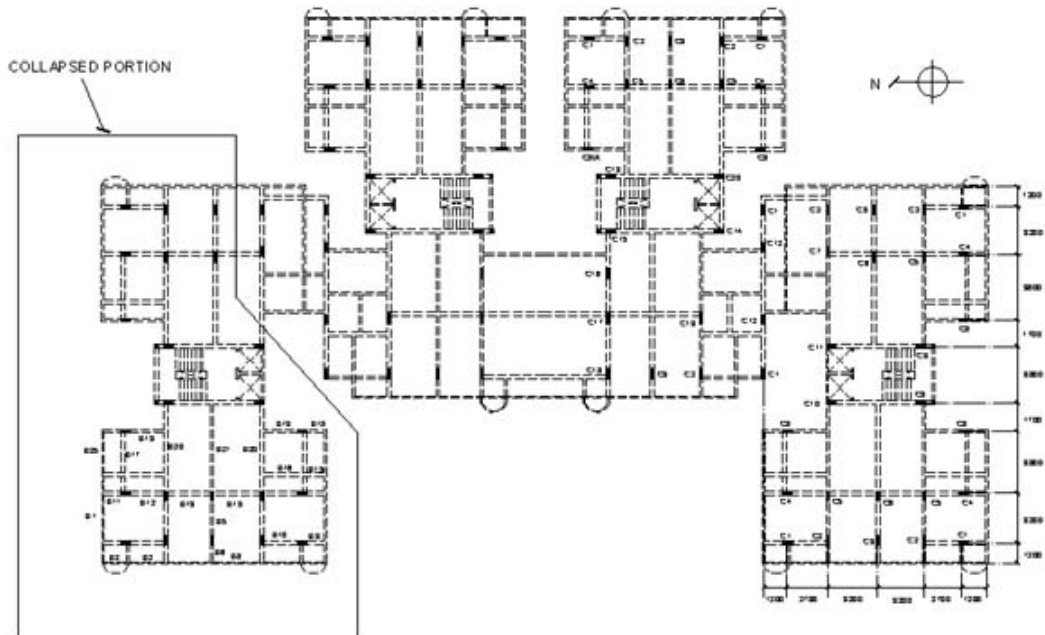


Figure 3: Plan of a Typical 10-story Building at Ahmedabad

4 Structural Features

4.1 Lateral Load-Resisting System

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.

4.2 Gravity Load-Bearing Structure

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.

4.3 Type of Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	
Masonry	Stone masonry walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	
		2	Massive stone masonry (in lime or cement mortar)	
	Earthen walls	3	Mud walls	
		4	Mud walls with horizontal wood elements	
		5	Adobe block or brick walls	
		6	Rammed earth/Pise construction	
	Unreinforced brick masonry walls	7	Unreinforced brick masonry in mud or lime mortar	
		8	Unreinforced brick masonry in mud or lime mortar with vertical posts	
		9	Unreinforced brick masonry in cement or lime mortar (various floor/roof systems)	
	Confined masonry	10	Confined brick/block masonry with concrete posts/tie columns and beams	
	Concrete block masonry walls	11	Unreinforced in lime or cement mortar (various floor/roof systems)	
		12	Reinforced in cement mortar (various floor/roof systems)	
		13	Large concrete block walls with concrete floors and roofs	
Concrete	Moment resisting frame	14	Designed for gravity loads only (predating seismic codes i.e. no seismic features)	
		15	Designed with seismic features (various ages)	
		16	Frame with unreinforced masonry infill walls	X
		17	Flat slab structure	
		18	Precast frame structure	
		19	Frame with concrete shear walls-dual system	
	Shear wall structure	20	Precast prestressed frame with shear walls	
		21	Walls cast in-situ	
		22	Precast wall panel structure	
		23	With brick masonry partitions	
Steel	Moment resisting frame	24	With cast in-situ concrete walls	
		25	With lightweight partitions	
		26	Concentric	
	Braced frame	27	Eccentric	
		28	Thatch	
Timber	Load-bearing timber frame	29	Post and beam frame	
		30	Walls with bamboo/reed mesh and post (wattle and daub)	
		31	Wooden frame (with or without infill)	
		32	Stud wall frame with plywood/gypsum board sheathing	
		33	Wooden panel or log construction	
		34	Building protected with base isolation devices or seismic dampers	
Various	Seismic protection systems	35		
	Other			

4.4 Type of Foundation

Type	Description	
Shallow Foundation	Wall or column embedded in soil, without footing	
	Rubble stone (fieldstone) isolated footing	
	Rubble stone (fieldstone) strip footing	
	Reinforced concrete isolated footing	X
	Reinforced concrete strip footing	
	Mat foundation	
	No foundation	
Deep Foundation	Reinforced concrete bearing piles	
	Reinforced concrete skin friction piles	X
	Steel bearing piles	
	Wood piles	
	Steel skin friction piles	
	Cast in place concrete piers	
	Caissons	
Other		

4.5 Type of Floor/Roof System

Material	Description of floor/roof system	Floor	Roof
Masonry	Vaulted		
	Composite masonry and concrete joist		
Structural Concrete	Solid slabs (cast in place or precast)	X	X
	Cast in place waffle slabs		
	Cast in place flat slabs		
	Precast joist system		
	Precast hollow core slabs		
	Precast beams with concrete topping		
	Post-tensioned slabs		
Steel	Composite steel deck with concrete slab		
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 single roof		
	Wood planks or beams that support clay tiles		
	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			

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

4.6 Typical Plan Dimensions

Additional Comments: 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.

4.7 Typical Number of Stories

5 - 10

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.

4.8 Typical Story Height

3.2 meters

Additional Comments: Story height varies between 2.8 m to 3.2 m depending upon plan dimensions and

type of housing constructions.

4.9 Typical Span

5.0 meters

Additional Comments: Span between columns of RC frame typically varies from 4.0 m to 6.5 m.

4.10 Typical Wall Density

5% - 7%

For typical buildings, density of masonry infill wall varies between 5% to 7% in each direction.

4.11 General Applicability of Answers to Questions in Section 4

This contribution is not based on a case study of one building.



Figure 4: Critical Structural Details

5 Evaluation of Seismic Performance and Seismic Vulnerability

5.1 Structural and Architectural Features: Seismic Resistance

Structural/ Architectural Feature	Statement	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.	X		
Building configuration	The building is regular with regards to both the plan and the elevation.		X	
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.	X		
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.	X		
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.	X		
Wall and frame structures-redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	X		
Wall proportions	Height-to-thickness ratio of the shear walls at each floor level is: 1) Less than 25 (concrete walls); 2) Less than 30 (reinforced masonry walls); 3) Less than 13 (unreinforced masonry walls).		X	
Foundation- wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	X		
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps.		X	
Wall openings	The total width of door and window openings in a wall is: 1) for brick masonry construction in cement mortar: less than 1/2 of the distance between the adjacent cross walls; 2) for adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; 3) for precast concrete wall structures: less than 3/4 of the length of a perimeter wall.		X	
Quality of building materials	Quality of building materials is considered to be adequate per requirements of national codes and standards (an estimate).		X	
Quality of workmanship	Quality of workmanship (based on visual inspection of few typical buildings) is considered to be good (per local construction standards).		X	
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber).		X	
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 Seismic Vulnerability Rating

Vulnerability						
	High (Very Poor Seismic Performance) A	B	Medium C	D	E	Low (Excellent Seismic Performance) F
Seismic Vulnerability Class		<	0		>	

- 0 - probable value
- < - lower bound
- > - upper bound



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

6 Earthquake Damage Patterns

6.1 Past Earthquakes Reported To Affect This Construction

Year	Earthquake Epicenter	Richter magnitude(M)	Maximum Intensity (Indicate Scale e.g. MMI, MSK)
1967	Koyna	6.7	VIII (MMI)
1993	Killari	6.4	VIII (MMI)
1997	Jabalpur	6.1	VII (MMI)
2001	Bhuj	7.6	X (MMI)

Additional Comments: 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 death 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 6H: Failure of Lower Two Stories of the Right Wing of an Apartment Building With Soft Storey; Note that the Left Wing Without Soft Storey is Apparently Undamaged (2001 Bhuj Earthquake)



Figure 6I: Under-Utilization of Shear Capacity of Elevator Core Due to Improper Diaphragm Action of Slabs Resulted in Failure 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 Multi-Storey Building Due to Weak Column-Strong Beam Design (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)

7 Building Materials and Construction Process

7.1 Description of Building Materials

Structural Element	Building Material	Characteristic Strength	Mix Proportions/ Dimensions	Comments
Infill Wall Brick (100 x 230 x 75 mm)	Burnt Clay	3.5-5 MPa		
Foundations	Concrete	15-20 MPa	1:2:4 to 1:1.5:3	
Frame				
Roof and floors	Concrete	15-20 MPa	1:2:4 to 1:1.5:3	
Beams and Columns	Concrete	15-20 MPa	1:2:4 to 1:1.5:3	
Reinforcing bar	Mild Steel High Strength Steel	230 MPa 415 MPa		

Notes:

- 1.
2. Generally, masonry mortar of 1:6 (cement:sand) is used for construction of partition walls ; dimensions of masonry brick is typically 230 mm (9") X 115mm (4.5") X 75 (3").

7.2 Does the builder typically live in this construction type, or is it more typically built by developers or for speculation?

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.

7.3 Construction Process

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 statutory clearances from the city officials. Due to the prevalent system, the structural engineer and the contractor/builder is typically not responsible for his work.

7.4 Design/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.

7.5 Building Codes and Standards

	Yes	No
Is this construction type addressed by codes/standards?	X	

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.

7.6 Role of Engineers and Architects

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.

7.7 Building Permits and Development Control Rules

	Yes	No
Building permits are required	X	
Informal construction		X
Construction authorized per development control rules	X	

7.8 Phasing of Construction

	Yes	No
Construction takes place over time (incrementally)		X
Building originally designed for its final constructed size	X	

7.9 Building Maintenance

Who typically maintains buildings of this type?	
Builder	
Owner(s)	X
Renter(s)	
No one	
Other	

7.10 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 statutory 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 liaising 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.

7.11 Typical Problems Associated with this Type of Construction

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 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.



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)

8 Construction Economics

8.1 Unit Construction Cost (estimate)

Typical cost of construction may range from Rs. 5000 - 7500 per m² (US\$ 100 - 150 per m²).

8.2 Labor Requirements (estimate)

Number of effort days required to complete the construction

9 Insurance

9.1 Insurance Issues

	Yes	No
Earthquake insurance for this construction type is typically available		X
Insurance premium discounts or higher coverages are available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features		X

9.2 If earthquake insurance is available, what does this insurance typically cover/cost?

10 Seismic Strengthening Technologies

10.1 Description of Seismic Strengthening Provisions

Type of intervention	Structural Deficiency	Description of seismic strengthening provision used
Retrofit (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 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.
New Construction	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.	

10.2 Has seismic strengthening described in the above table been performed in design practice, and if so, to what extent?

Only high rise buildings or buildings rendering important services are seismically strengthened as per the standard practice

10.3 Was the work done as a mitigation effort on an undamaged building, or as repair following earthquake damage?

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.

10.4 Was the construction inspected in the same manner as new construction?

No

10.5 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.

10.6 What has been the performance of retrofitted buildings of this type in subsequent earthquakes?

Data not available.

11 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.

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Country	India	India	India
Phone	91-22-5722545 ext. 8389	(91-22) 576-7336	91-22-576-7342
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13 Figures



Figure 1: Typical Building