16 Postearthquake Handling of Buildings

INTRODUCTION

The Bhuj earthquake was the first damaging earthquake to hit an urban area of India and cause collapse of multistory buildings. The country in general, and Gujarat in particular, was not prepared to face an engineering challenge of this kind. This chapter highlights some of the aspects of post-earthquake handling of buildings—immediate need for bracing, initial and comprehensive damage surveys, retrofit challenges, and reconstruction policy.

IMMEDIATELY AFTER THE EARTHQUAKE

The earthquake caused maximum shaking intensity of X and IX on the MSK scale in parts of the district of Kachchh. Ahmedabad (about 200 km from the epicenter) experienced shaking intensity VII. Even though there were far more collapses and deaths in the Kachchh district, the initial focus after the earthquake was on Ahmedabad, it being a major business center and adjacent to the state capital Gandhinagar.

INITIAL BUILDING SURVEY IN AHMEDABAD

In Ahmedabad, with numerous building collapses and loss of life, the first few days after the earthquake were spent on rescue and relief, while total confusion prevailed regarding buildings that were still standing. Residents were scared and did not want to stay inside the buildings. An immediate task was to restore the confidence of residents about the safety of buildings by carrying out a quick survey of the buildings still standing. Hardly any expertise on earthquake issues was available in Ahmedabad at the time of the earthquake, and even the published manuals and monographs on earthquake engineering did not seem to be available to the concerned officials and engineers.

The next day, January 27, under the banner of Gujarat Institute of Civil Engineers and Architects (GICEA), local engineers began inspecting buildings that were still standing in Ahmedabad and classifying them according to damage. This was done in response to requests made by building owners or residents for damage assessment. This classification naturally was quite subjective, since a uniform assessment criterion was not provided to the engineers conducting these inspections.

On the morning of January 31, five days after the earthquake, two structural engineers from Hyderabad reached Ahmedabad and started providing informal advice to local administrators. They also brought along the published guidelines, booklets, and Indian seismic codes and provided them to the authorities.

For weeks after the earthquake, it was a confusing time for residents. People wanted a quick solution for the safety of their building, and lacked confidence in local builders and engineers. Numerous visitors and experts were visiting the buildings and taking pictures. Some visitors gave conflicting oral advice, while many others resisted giving any advice; this sometimes made residents feel frustrated with the visitors.

CHARGES BROUGHT AGAINST BUILDERS, CONTRACTORS, AND ENGINEERS

Soon after the earthquake, the anger of the local population in Ahmedabad was directed towards the builders and structural engineers who had been responsible for the unsafe buildings. Starting February 2, criminal cases were filed against them by the affected individuals. The state government took a fairly tough stand on this. Builders, contractors, and structural engineers connected with construction of about 70 buildings in Ahmedabad that collapsed and caused deaths were charged under criminal law (Indian Penal Code Section 304) for "culpable homicide not amounting to murder." As per Section 304, intention is not essential and knowledge is sufficient. The case is based on the act of omission. If convicted, punishment is imprisonment for up to 10 years. Charges under this clause meant that the persons arrested could not be released on bail till July 2001. In July, in a bail hearing in the Gujarat High Court, the government counsel agreed to change the charges to Section 304A ("rash and negligent act of killing," similar to cases of road accidents); conviction would mean up to two years of imprisonment. Based on this assurance, the Gujarat High Court granted bail to the imprisoned. In all, about 120 engineers and builders in Ahmedabad were imprisoned.

Among those arrested was also a municipal official. The rest of the concerned municipal officials were booked and charge-sheeted, but not arrested, on some technical ground. It seems that after arresting the first municipal official, concern may have developed regarding demoralization of a large body of municipal officials who would be needed to handle the emergency situation.

With criminal cases and arrests in the air, many builders and engineers connected with the collapsed buildings went underground for fear of arrest. Moreover, structural drawings of the buildings, much needed at that stage, became unavailable. The residents who bought individual flats did not have the structural drawings, the local authorities did not require submission of drawings by engineers, so none was on file and publicly available. Builders would not part with their drawings for fear of prosecution.

DAMAGE ASSESSMENT IN AHMEDABAD

As mentioned earlier, immediately after the earthquake, the local officials and members of the Gujarat Institute of Civil Engineers and Architects (GICEA) began a quick survey of the buildings without uniform criteria for damage classification. Experts from outside the area, on reaching Ahmedabad on February 3, emphasized the need for objective damage assessment criteria. The following day, February 4, more experts from around the country, including Dr. A.S. Arya, Emeritus Professor, Indian Institute of Technology Roorkee, reached Ahmedabad, and criteria were evolved for building damage classification for RC buildings followed by those for other buildings. In the Latur (India) earthquake of 1993, most of the damaged buildings consisted of stone masonry and the damage classification criteria as per MSK intensity scale was adopted (G0 to G5, with G0 meaning no damage and G5 meaning collapse). This damage classification was modified for Gujarat (Tables 16-1 through 16-3) by the expert group under the chairmanship of Dr. A.S. Arya to cover RC frame buildings, load bearing masonry buildings, and load bearing wooden frame buildings.

Local authorities in Ahmedabad realized that the damage classification should be done by a fairly independent agency. Therefore, the Center for Environmental Planning and Technology (CEPT) at Ahmedabad was entrusted with the job of carrying out the damage assessment survey for multistory residential buildings in Ahmedabad. CEPT is an institute for education in architecture, town planning, and building science. Even though they had no prior experience in earthquake issues, and had very little manpower considering the job requirements, CEPT leadership agreed to

Table 16-1. Categorization scale adopted for evaluation of reinforced concrete frame buildings damaged in Gujarat

Category	Damage	Extent of damage in nonengineered component	Extent of damage in RC column: Individual column	Extent of damage in RC column: All columns in ground story	Suggested postearthquake action
0	None	No damage	No damage or visual cracks	No damage	Seismic strengthening is required for long-term seismic safety.
G1	Slight non-structural damage	Thin cracks in plaster, falling of plaster bits in limited parts	Very fine cracks in columns, which are to be seen with much attention.	40%-50% of columns with G1; rest in Category 0	Remove plaster across cracks and replaster. Building need not be vacated. Seismic strengthening is required for long-term seismic safety.
G2	Slight structural damage	Small cracks in walls, falling of plaster in large bits over large areas; damage to non-structural parts, such as chimneys, projecting cornices, etc. The load carrying capacity of the structure is not reduced appreciably.	Wider cracks in column, approaching 1 mm width, going through core of column. Visible to eye.	40%-50% in G2; rest in Category G1	Remove plaster and grout cracks using epoxy or similar materials. Building need not be vacated. Seismic strengthening is required for long-term seismic safety .
G3	Moderate structural damage	Large and deeps cracks in walls. Widespread cracking of walls, columns and piers and tilting or falling of chimneys. The load carrying capacity of structure is partially reduced.	Cracks in column at top and within height approaching 2 mm width, with some crushing of concrete at the cracks, but without relative movement between two parts.	40%-50% in G3; rest in Category G2	Building needs to be vacated. To be reoccupied after restoration and strengthening. Structural restoration and seismic strengthening necessary before reoccupation.
G4	Severe structural damage	Gaps occur in walls; inner or outer walls collapse; failure of ties to separate parts of building. Approximately 50 percent of the main structural elements fail. The building is in a dangerous state.	Diagonal cracks/ torsional cracks/ substantial crushing of concrete. Buckling of reinforcement; ‘through’ wide cracks in column includ ing relative movement in parts of column and floor.	40%-50% in G4; rest in Category G3	Building needs to be vacated. Either building has to be demolished or extensive restoration and strengthening work has to be done before reoccupation.
G5	Collapse	A large part or the entire building collapses.	A large part or the entire building collapses.		Cleaning the site and reconstruction.

Table 16-2. Categorization scale adopted for evaluation of load-bearing lowrise buildings in Ahmedabad City

Category	Damage	Extent of damage in bearing walls	Suggested postearthquake action
0	None	No damage	Building need not be vacated. Seismic strengthening is advised for long-term seismic safety.
G1	Slight non-structural damage	Thin cracks in plaster, falling of plaster bits in limited parts.	Remove plaster across cracks and replaster. Building need not be vacated. Seismic strengthening is advised for long-term seismic safety.
G2	Slight structural damage	Small cracks in walls, falling of plaster in large bits over large areas; damage to nonstructural parts, such as flooring, parapets, dado, etc. The load carrying capacity of the structure is not reduced appreciably	Building need not be vacated. Removed plaster and grout cracks with cement slurry or cement and sand (1:3 mixed mortar), depending on width of the crack. Rebuild $h/b \leq 3$. If taller, provide reinforcement tied to structural slab parapets. Repair various structural elements. Seismic strengthening is advised for long-term seismic safety.
G3	Moderate structural damage	Large and deep cracks in walls; widespread cracking of walls, tilting of walls, posts tilted or damaged piers cracked or tilted; joist bent and/or cracked. The load carrying capacity of the structure is partially reduced.	Building needs to be vacated. It can be reoccupied after restoration and strengthening. Structural restoration and seismic strengthening necessary before reoccupation.
G4	Severe structural damage	Gaps occur in walls; inner or outer walls collapse. Approximately 50 percent of the main structural elements, such as posts, joists, binders, and girders fail. The building is in a dangerous state.	Building needs to be vacated. Either the building has to be demolished or extensive restoration and strengthening has to be carried out before reoccupation
G5	Collapse	A large part or the entire building collapses.	Cleaning the site and reconstruction.

Table 16-3. Categorization scale adopted for evaluation of load-bearing lowrise wooden frame structures damaged in the Walled City of Ahmedabad

Category	Damage	Extent of damage in non-engineered component	Suggested postearthquake action
0	None	No damage	Building need not be vacated. Seismic strengthening is required for long-term seismic safety.
D1	Slight non-structural damage	Thin cracks in plaster, falling of plaster bits in limited parts.	Remove plaster across cracks and redo plaster. Building need not be vacated. Seismic strengthening required for long-term seismic safety.
D2	Slight structural damage	Small cracks in walls, falling of plaster in large bits over large areas. Masonry separates from wooden structural members. Damage to nonstructural parts, such as flooring, parapets, dado, etc. and decorative elements and finishes. The load carrying capacity of the structure is not reduced appreciably.	Building need not be vacated. Remove plaster and grout cracks with lime, sand, and *surkhi*[1] (1:1:1 mixed mortar) or 1:3 cement and sand mortar, depending on width of the crack. Rebuild cornices, parapets, and other decorative elements. Repair various structural elements. Prop the structure wherever required until the restoration work starts. Seismic strengthening required for long-term seismic safety.
D3	Moderate structural damage	Large and deep cracks in walls; widespread cracking of walls, tilting of walls, posts tilted or damaged, piers cracked or tilted, joists bent and/or cracked. Failure of joints between wooden structural members is evident. The carrying capacity of the structure is partially reduced.	Building needs to be vacated. It can be reoccupied after restoration and strengthening. Prop the structure required until the restoration work starts. Structural restoration and seismic strengthening necessary before reoccupation.
D4	Severe structural damage	Gaps occur in walls; inner or outer walls collapse. Approximately 50 percent of the main structural elements, such as posts, joists, binders, and girders fail. The building is in a dangerous state.	Building needs to be vacated. Building has to be systematically dismantled and all the elements worthy of reuse to be retrieved and extensive restoration and strengthening work has to be carried out before reoccupation.
D5	Collapse	A large part or the entire building collapses.	Cleaning the site and reconstruction. All the elements worthy of reuse to be retrieved from the debris.

[1] *Surkhi* is the powder of burnt clay bricks, and acts as an artificial pozzolana.

take up the assignment on a direct cost reimbursement basis in the spirit of public service. The cooperative societies of multistory residential buildings had to apply by a certain cut-off date to request a free survey of their building. CEPT conducted damage surveys of about 6,670 buildings.

CEPT issued an appeal to structural engineers across India to come forward and volunteer their services to help with the damage assessment. The engineering community responded well, and about 160 senior structural engineers from different parts of the country (e.g., Delhi, Kolkata, Mumbai, Indore, Pune, Bangalore, Chennai, Kochi, Vishakhapatnam, in addition to different towns of Gujarat) participated. Typically, engineers from out of the area spent about a week in Ahmedabad, and in the process gained a lifetime experience of learning from real earthquake damage. Volunteer engineers were reimbursed for their travel expenses, provided local hospitality, and a nominal honorarium. In addition, about 80 senior students (postgraduate or undergraduate final year) of several engineering colleges in Gujarat and another 30 junior engineers contributed towards the damage assessment by CEPT in Ahmedabad. Figure 16-1 shows the form used by CEPT for the rapid assessment. It is a question for debate whether it would have been better to have the damage survey done by paid structural engineers rather than by the volunteer engineers.

A typical damage survey team from CEPT consisted of:

- A senior structural engineer
- A junior engineer, who could also be a senior student of civil engineering
- One cameraman to take pictures
- One representative of the local authorities for liaison

This team was given a vehicle and a driver. On the first day, the team was given a one-and-a-half hour orientation on use of the damage survey forms. On a typical day, about 20-25 such teams were out surveying, with each team completing about 10 buildings. At the end of the day, the senior engineer would submit the damage assessment forms along with his recommendation on the damage grade, to the central unit at CEPT. A smaller group of six or seven persons at CEPT then carefully scrutinized the forms before awarding the final damage grade.

The damage assessment survey began on February 5 and continued for almost three months. The field visits and filling of forms took the first one and half months, while the remaining time was spent finalizing the recommendations and grading. Since the financial aid from the government for repair and rehabilitation of buildings was linked with the damage category, the buildings in Ahmedabad not covered by CEPT were surveyed by other agencies. In view of the financial aid, there were instances of the beneficiaries putting pressure to have their property classified in a higher damage category.

DAMAGE ASSESSMENT IN KACHCHH DISTRICT

Compared to the situation in Ahmedabad, the building industry in Kachchh district was even less professional. Even though there were building bylaws for towns in the Kachchh region, they were generally not followed, even with regard to floor area that can be built on a given plot size. Permissions were routinely given for construction of buildings of ground floor plus seven stories. It seems that after the earthquake, during one of the legal proceedings, the Bhuj municipality officials pleaded that they were not aware that the town is in Seismic Zone V and had never received any circular from the state government regarding matters of earthquake safety. The four towns of the Kachchh district now restrict buildings to ground plus two stories.

Ahmedabad, 200 km from the epicenter, had a relatively smaller ratio of building stock that collapsed or was severely damaged than did the towns of the Kachchh district, which was at the epicenter. By an approximate estimate, Ahmedabad has about 1,500 RC frame buildings of around 10 stories, and more than 25,000 RC frame buildings of five stories; of these, 2 and ~130 buildings,

Rapid Evaluation Safety Assessment Form

Centre For Environmental Planning & Techonlogy, Ahmedabad

Team details:

________________ Civil Engineer/Structural Engineer
________________ Architect
________________ Senior Student
________________ Officer, AMC

Inspection Details:

Date: ________________
Time: ________________

Building Description:

Building Name: ________________
Address: ________________
____
Building contact/phone: ________________
Number of stories above ground:____ below ground: ____
Approx. 'Footprint area'(smt.): ________
Number of residential units: ________________
Number of residential units not habitable:________

Type of Construction:

☐ Wood Frame ☐ Concrete Shear Wall
☐ Steel Frame ☐ Unreinforced Masonry
☐ Tilt-up concrete ☐ Reinforced Masonry
☐ Concrete Frame ☐ Other: ________

Primary Occupancy:

☐ Dwelling ☐ Commercial ☐ Government
☐ Other resi. ☐ Offices ☐ Historic
☐ Public Assembly ☐ Industrial ☐ School
☐ Emergency Ser. ☐ Other:________

Evaluation:

Investigate the building for the conditions below and check the appropriate column

Observed Conditions	**Minor/none**	**Moderate**	**Severe**
• Collapse, partial collapse, or building off foundation			
• Building or story leaning	☐	☐	☐
• Racking damage to walls, other str. damage	☐	☐	☐
• Chimney, parapet, or other falling hazard	☐	☐	☐
• Other, (specify)	☐	☐	☐

• Comments: ________________________________
____

Distressed Developed in Columns:

• ***Cracks*** *At the junction of Beam-column*
☐ Corner Nos. ____ ☐ Peripheral Nos. ____
☐ Inner Columns Nos. ____ ☐ Near Stair Nos. ____

Plaster cracked / plaster cracked
☐ Corner Nos. ____ ☐ Peripheral Nos. ____
☐ Inner Columns Nos. ____ ☐ Near Stair Nos. ____

• ***Inclined Cracks*** *about 45 deg. to horizontal*
☐ Corner Nos. ____ ☐ Peripheral Nos. ____
☐ Inner Columns Nos. ____ ☐ Near Stair Nos. ____

• ***Vertical Cracks*** *along location of main steel*
☐ Corner Nos. ____ ☐ Peripheral Nos. ____
☐ Inner Columns Nos. ____ ☐ Near Stair Nos. ____

Others
☐ Corner Nos. ____ ☐ Peripheral Nos. ____
☐ Inner Columns Nos. ____ ☐ Near Stair Nos. ____

• ***Buckling of Bars***
☐ Corner Nos. ____ ☐ Peripheral Nos. ____
☐ Inner Columns Nos. ____ ☐ Near Stair Nos. ____

• ***Concrete crushed***
☐ Corner Nos. ____ ☐ Peripheral Nos. ____
☐ Inner Columns Nos. ____ ☐ Near Stair Nos. ____

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Figure 16-1. Form used by CEPT for the rapid assessment of buildings in Ahmedabad.

Centre For Environmental Planning & Techonlogy, Ahmedabad

Distressed Developed in Beams at First Floor Level:

- ***Cracks*** *Inclined near support*
  - ☐ Peripheral Nos. ______ ☐ Others Nos. ___
  - ☐ Beams supporting stub columns Nos. ___

  Vertical Mid Span
  - ☐ Peripheral Nos. ______ ☐ Others Nos. ___
  - ☐ Beams supporting stub columns Nos. ___

  Vertical Near Mid Span
  - ☐ Peripheral Nos. ______ ☐ Others Nos. ___
  - ☐ Beams supporting stub columns Nos. ___

  Vertical Near Support
  - ☐ Peripheral Nos. ______ ☐ Others Nos. ___
  - ☐ Beams supporting stub columns Nos. ___

  Horizontal Parallel to Reinforcement
  - ☐ Peripheral Nos. ______ ☐ Others Nos. ___
  - ☐ Beams supporting stub columns Nos. ___

  Horizontal Others
  - ☐ Peripheral Nos. ______ ☐ Others Nos. ___
  - ☐ Beams supporting stub columns Nos. ___

Distressed Developed in Beams for other Floor Level:

- ***Cracks*** *Inclined near support*
  - ☐ Peripheral Nos. ______ ☐ Others Nos. ___

  Vertical Mid Span
  - ☐ Peripheral Nos. ______ ☐ Others Nos. ___

  Vertical Near Mid Span
  - ☐ Peripheral Nos. ______ ☐ Others Nos. ___

  Vertical Near Support
  - ☐ Peripheral Nos. ______ ☐ Others Nos. ___

  Horizontal Parallel to Reinforcement
  - ☐ Peripheral Nos. ______ ☐ Others Nos. ___

  Horizontal Others
  - ☐ Peripheral Nos. ______ ☐ Others Nos. ___

Distressed Developed in slabs :

• ***Floor***	☐ *Cracks*	☐ *Delamination*	☐ *Spalling*
• ***First Floor***	☐ *Cracks*	☐ *Delamination*	☐ *Spalling*
• ***Second Floor***	☐ *Cracks*	☐ *Delamination*	☐ *Spalling*
• ***Upper Floors***	☐ *Cracks*	☐ *Delamination*	☐ *Spalling*

Distressed Developed in Stair :

- ***Cracks***

Flight	☐ *Perpendicular to Flight*	☐ *Along the Flight*	☐ *Separation from wall*
Landing	☐ *Perpendicular to Flight*	☐ *Along the Flight*	

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Figure 16-1. *(Continued)* Form used by CEPT for the rapid assessment of buildings in Ahmedabad.

Centre For Environmental Planning & Techonlogy, Ahmedabad

Distressed Developed in Walls :

- ***Lift Wall*** ☐ *RCC* ☐ *Columns with infilling bk.walls* ☐ *Bk. wall*

Cracks ☐ *Vertical* ☐ *Diagonal* ☐ *Spalling of concrete etc.*

- ***Load Bearing Walls*** ☐ *230 mm* ☐ *350 mm*

Peripheral

Cracks ☐ *Thin Vertical* ☐ *Thin Horizontal* ☐ *Thin Diagonal* ☐ *Thin Toothing* ☐ *Thin Cross*

Cracks ☐ *wtt.* Vertical* ☐ *wtt. Horizontal* ☐ *wtt. Diagonal* ☐ *wtt. Toothing* ☐ *wtt. Cross*

**wtt. Wide through and through*

- ***Partition Walls*** ☐ ***150mm*** ☐ ***115 mm***

External

Cracks ☐ *Thin Vertical* ☐ *Thin Horizontal* ☐ *Thin Diagonal* ☐ *Thin Toothing* ☐ *Thin Cross*

Cracks ☐ *wtt.* Vertical* ☐ *wtt. Horizontal* ☐ *wtt. Diagonal* ☐ *wtt. Toothing* ☐ *wtt. Cross*

Internal

Cracks ☐ *Thin Vertical* ☐ *Thin Horizontal* ☐ *Thin Diagonal* ☐ *Thin Toothing* ☐ *Thin Cross*

Cracks ☐ *wtt.* Vertical* ☐ *wtt. Horizontal* ☐ *wtt. Diagonal* ☐ *wtt. Toothing* ☐ *wtt. Cross*

- **Observations other than above pertaining to distress**

Whether propped ☐ *yes* ☐ *No*

So called Rehabilitation started ☐ *yes* ☐ *No* ☐ *work in progress*

☐ **No distress observed**

☐ **Minor distress observed in few structural members, which can be repaired under the advice of Structural Consultant**

☐ **Medium distress observed in some of the structural members, which can be rehabilitated including strenghtening, if required, under the advice of Structural Consultant**

☐ **Severe distress observed in some of the structural members, which can be rehabilitated including strenghtening under the advice of Structural Consultant**

____

Team Leader
Structural Engineer/Civil Engineer

Figure 16-1. *(Continued)* Form used by CEPT for the rapid assessment of buildings in Ahmedabad.

Table 16-4. Damage statistics in percentages in towns of Kachchh district

Town	Intensity	Distance from Epicenter	Damage Grade				
			G1	G2	G3	G4	G5
Bhachau	X	13 km	0.0	0.0	0.9	0.7	98.4
Rapar	IX	33 km	3.1	11.2	21.0	31.9	32.7
Anjar	IX	41 km	35.5	12.7	12.7	6.7	32.4
Gandhidham	IX	44 km	47.4	22.6	12.9	8.5	8.5
Bhuj	IX	63 km	16.0	19.2	18.3	20.5	25.7
Mandvi	VIII	109 km	58.5	21.5	8.5	8.4	3.2
Total			29.2	17.4	14.1	13.1	26.2

respectively, collapsed during the earthquake. The percentage of building collapses in Bhuj and other towns of Kachchh district was far higher (Table 16-4). Ahmedabad had relatively better availability of structural engineering expertise locally, as well as in terms of outside experts after the earthquake (e.g., Mankad, 2001). Moreover, Ahmedabad, being a more prominent town and just adjacent to the capital Gandhinagar, attracted more urgent attention of the administration. As a result, even though the damage survey criteria and the survey forms were developed for Ahmedabad and used starting February 5, it was almost another month before the damage survey was started at Bhuj.

Like in Ahmedabad, in Bhuj also criminal cases were filed against structural engineers and builders, and some were arrested. One engineer remained in jail without bail for about 4 months. Many others were arrested much later and allowed bail within a few days of arrest.

SHORT-TERM RETROFITTING

Considering the panic and fear of falling buildings, the local engineers and builders started strengthening buildings as they deemed appropriate, even though most of them did not have a prior experience of seismic issues. This is a peculiar aspect of the civil engineering profession. The local engineers and builders could not wait for the outside experts to come and advise them on methods of seismic retrofitting. They simply had to do something to save the buildings from collapse during the aftershocks and to restore the confidence of residents. Since the region had no serious compliance with the seismic codes, the local engineering community was only oriented towards design of structures for gravity loads. Immediately after the earthquake, the GICEA in Ahmedabad issued a guide on repair and strengthening of buildings. Again, this guide addressed the issues related to giving vertical support to the building, and did not include providing lateral strengthening against future earthquakes.

Seeing the collapses in Ahmedabad, seismic vulnerability of open ground story buildings (soft story buildings), not appreciated by professional engineers and architects in India over the years, became immediately obvious to both professionals and laypersons. Hence, in the immediate aftermath, the focus was on strengthening the ground story columns, usually by jacketing. However, even this left much to be desired. Some of the quick retrofit measures on multistory buildings later invited criticism from outside experts who often did not appreciate the conditions under which the local building industry had to operate after the earthquake. This had a demoralizing effect on the local structural engineers.

About six weeks after the earthquake, the Ahmedabad Municipal Corporation held a meeting of about 40 structural engineers from Ahmedabad and outside and developed some seismic strengthening guidelines. The focus of the recommendations made on the lowrise RC frame buildings was to provide brick masonry infills in the open ground stories. Since then, many building owners and contractors have adopted this as the strengthening technique. However, the entire exercise of retrofitting of multistory buildings in Ahmedabad remains quite empirical and without proper structural calculations. This is possibly due to inadequate seismic expertise in the area and the limited financial means of the residents to hire experienced structural consulting firms.

RETROFIT SCHEMES

The various retrofit schemes adopted in Ahmedabad and other areas of the State of Gujarat include:

- Point and re-plaster of cracked infill walls and columns (Figure 16-2).
- Replace all the infill walls in the RC frame panels (Figures 16-3 and 16-4).
- Jacket RC columns in the open ground story (Figures 16-5 and 16-6). In many cases of column jacketing, the new reinforcement was not anchored into the foundations or the building frame, and the plaster on the old concrete column surface was not removed.
- Prop beams with masonry pillars, or steel joists or built-up sections (Figure 16-7).
- Provide steel braces in open bays (Figure 16-8).
- Prop cantilever beams supporting the perimeter floating columns with masonry columns, steel joists, or masonry walls (Figure 16-9).
- Infill the previously open RC frame panels in the ground story with masonry infills (Figure 16-10).

Figure 16-2. Numerous buildings in the affected area sustained only frame-infill separation. In most of these cases, the separations were cleaned and filled with rich cement mortar. The above picture shows the repair done at a school building in Gandhidham.

Figure 16-3. Large block sandstone masonry infills in cement mortar at a two-story school building in Ahmedabad were completely replaced with burnt-clay brick masonry infills in cement mortar.

Figure 16-4. The large panel burnt-clay brick masonry infills in cement mortar, sustained partial collapse at the upper story of the three-story telephone exchange building in Bhuj. The infills of the entire building, including those at the lower stories, were replaced with lightweight foam concrete panels sandwiched between asbestos sheets. These panels were secured to the frame with thin steel straps.

Figure 16-5. Jacketing of a rectangular column of the ground story of a seven-story old age home in Gandhidham, was performed from the floor level to a level well below the beams at the top of that column. The column bars are seen curtailed by the side of the beam.

Figure 16-6. The circular RC column in the ground story of an 11-story (including a basement story) commercial building in Ahmedabad is jacketed with hot-rolled I-sections with ties to hold it adjoining the concrete column. There are no connections between the RC column and the steel I-section.

Figure 16-7. RC columns of the three-story residential RC frame building in Gandhidham are adjoined with brick masonry columns from the floor level to the beam soffit. The beam is propped at intermediate locations with hot-rolled steel I-sections.

Figure 16-8. Steel braces are employed in limited cases to strengthen the open ground story panels. This picture shows bracing employed in addition to the infilling with burnt-clay brick masonry infills and jamming of steel sections at the outer faces, in a residential building. The bracing member used is a steel hollow box-section of 100 size with 8 mm plate thickness.

Figure 16-9. RC frame buildings with open ground stories usually have overhanging beams along the perimeter in the ground storey. Many of these cantilevers sustained shear cracks during the earthquake. In this building, masonry columns were constructed under the tips of these beams as a retrofit measure.

Figure 16-10. In this RC frame building with open ground story masonry infills were provided in select panels of the ground story without hampering parking in the open ground story.

JACKETING COLUMNS

Jacketing of RC columns in the ground story is the most common measure being adopted. In most cases, the additional concrete and reinforcement is just added around the old column (Figure 16-5), and in some cases, the old column is snugly strapped with steel angles and flats (Figure 16-11) and then the concreting is done. There was at least one building in Ahmedabad, where immediately after the earthquake, the columns in the ground story were jacketed to an unusually large size (Figure 16-12). In many cases, the jacketing has been done without removing the plaster, if any, or roughening the surface of the old column. Jacketing often starts from the finished ground floor level as against the foundation. In some cases, the jacketing has been started from the foundation (Figure 16-13). Furthermore, the longitudinal bars added in the additional concrete portion are often left projecting out without any connection to the older RC beam and column members above (Figure 16-5).

EXEMPLARY RETROFIT

Amidst all this chaotic, prescriptive and owner-driven "retrofit" activity, there have been rare examples of more formal retrofit of building. One building, of RC frame with infills in the upper story and an open ground story, sustained shear damage to the ground story columns and nominal frame-infill separation in the upper stories. The owners of individual apartments got together and undertook the task of retrofitting. The steps adopted in this apartment owner-driven retrofit program include:

- Fill epoxy in column cracks.
- Gunite the cracked column faces.
- Rebuild individual footings—modify the 1.2 m × 1.2 m tapered footings to 1.8 m × 1.8 m × 0.6 m thick rectangular footings.
- Add tie beams between columns at the top of the modified footing.
- Add masonry walls over the tie beams in select bays of the open ground story panels.
- Add masonry walls under the cantilever beams that support the floating columns in the ground story.

In all, the retrofit of the 42-column structure consumed 1,800 bags of cement and about 11 metric tons of reinforcing steel; a total expenditure of about Rs. 2 million was incurred.

IMPEDIMENTS TO RETROFIT

Sound seismic retrofit in the affected area is hampered by the following:

- Lack of perspective, even now, on seismic issues. For instance, it is not uncommon to hear people argue that this earthquake has released the seismic energy, and there is no chance of another damaging earthquake in the area for a very long time.
- Some argue that India is a developing country and cannot afford to (and hence, should not) invest in retrofitting.
- Lack of expertise in seismic engineering in the local engineering community. Even after the earthquake, not enough comprehensive trainings have been conducted for structural engineers in seismic engineering. The detailed guidelines, manuals, and other resource materials that could guide a structural engineer have not yet been developed.
- Financial constraints. Most multistory apartment blocks are built by a developer, who then sells individual flats to the residents. Most of the residents buy the apartments with loans and with their life's savings. Hence, it is very difficult for the residents of multistory buildings to pool enough money to adequately retrofit the building, and the cash assistance provided by the government is often inadequate for carrying out comprehensive retrofitting.
- Lack of a clear policy statement on seismic retrofitting of buildings.

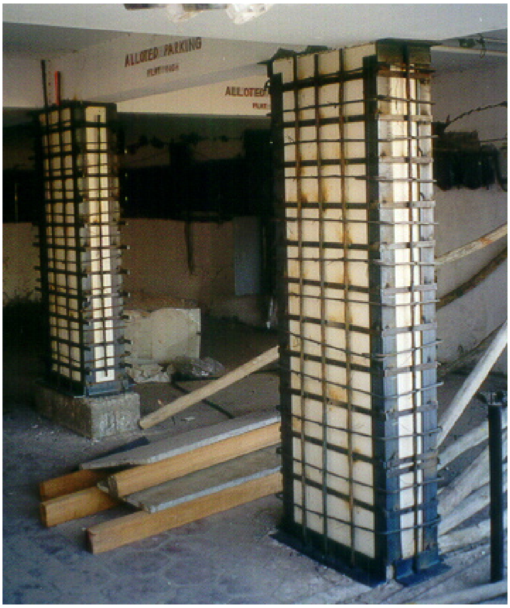

Figure 16-11. Mild steel angles of 75 mm size at four corners and 25 mm steel flats as battens were employed as the primary reinforcement for damaged RC columns of this open ground story building before jacketing them.

Figure 16-12. The open ground stories in RC frame buildings were intended to provide parking in the ground story. In some cases, this function was hampered after jacketing, because the size of the jacketed columns did not leave much space for movement, particularly for cars.

Figure 16-13. Instances where column jacketing was started at the footing level were few. Even in these cases, the column reinforcement may not have been anchored into the footing and even the footing may not have been enhanced.

RECONSTRUCTION IN STATE OF GUJARAT

The entire reconstruction and rehabilitation project in Gujarat is owner-driven. Residents are themselves responsible for repairs, strengthening or rebuilding of their own houses. The Government of Gujarat (GoG) provides only cash relief and some technical assistance. Several aid packages have been implemented by the GoG for building activities: different for rural and urban areas, and different for urban areas of Kachchh district versus for those of other districts.

Aid Package 1

Meant for villages where more than 70 percent of structures were damaged. Such villages may be relocated with the consent of the villagers and the *Gram Sabha* (village council). In the new village, the beneficiaries will be entitled to the plot size and the built-up area as per Table 16-5. In addition, the cost of land acquisition and primary infrastructure will be provided. For categories 3 and 4 in Table 16-5, 10 percent of the cost of house will be considered as an interest-free loan, payable in installments over 10 years with a moratorium period for first two years. The cost for an entire village of 200 families (approximate population of 1,000 persons) for land, infrastructure, and the cost of construction is estimated to be about Rs. 30 millions.

Table 16-5. Assistance for Aid Pacakge 1

S.No.	Category	Plot Area (m^2)	Construction Area (m^2)
1	Landless agricultural laborers	100	30
2	Marginal farmers up to 1 hectare land holding	150	40
3	Small farmers between 1 to 4 hectares land holding, small traders and artisans and others	250	40
4	Farmers with more than 4 hectares land holding	400	50

Aid Package 2

Covers villages in the meizoseismal area. Villages are not to be relocated. Compensation provided by the government will be as per Tables 16-6 and 16-7. The 40 percent amount is to be disbursed at preparatory level, 40 percent when construction/repair has reached the lintel level, and the balance 20 percent after the completion of construction.

Table 16-6. Assistance for completely damaged houses in Aid Package 2

S.No.	Type of Damage	Assistance
1	Completely destroyed hut	Rs.40,000 per unit
2	Completely destroyed house	
	(a) the built up area is up to 25 m^2	Up to Rs. 50,000
	(b) the existing built up area is up to 35 m^2	Up to Rs. 70,000
	(c) the existing built up area is up to 45 m^2	Up to Rs. 90,000

Table 16-7. Assistance for partially damaged houses in Aid Package 2

S.No.	Type of Damage	Assistance
1	If there are cracks of at least ½ inch width	Up to Rs. 3,000
2	Damage up to 10 %	Up to Rs. 7,000
3	Damage up to 25 %	Up to Rs. 15,000
4	Damage up to 50 %	Up to Rs. 30,000

Aid Package 3

Meant for villages away from the epicentral region. Cash assistance in this category is as per Tables 16-8 and 16-9.

Table 16-8. Assistance for totally/partially damaged huts in Aid Package 3

S.No.	Type of Damage	Assistance
1	Completely destroyed hut	Rs. 7,000
2	Partially damaged hut	Rs. 2,000

Table16-9. Assistance for completely destroyed/partially damaged houses in Aid Package 3

S.No.	Type of Damage	Assistance
1	If there are cracks of at least ½ inch width	Up to Rs. 2,000
2	For repair of damage up to 10%	Up to Rs. 5,000
3	For repair of damage up to 25%	Up to Rs. 10,000
4	For repair of damage up to 50%	Up to Rs. 20,000
5	Completely damaged kachcha/ pukka house	Up to Rs. 40,000

Aid Package 4(a)

For RC buildings in urban areas, excluding those in the four towns of Bhuj, Anjar, Bhachau, and Rapar (all four in the Kachchh district). For buildings that collapsed or had to be pulled down for safety reasons, assistance at the rate of Rs. 3,500 per square meter for up to 50 square meters (that is, up to Rs. 175,000) will be paid. This is not available if a person owns any other house in her/his own name or in the name of her/his dependents. Repair of non-multistory RC buildings, the assistance will be as per Table 16-10. For damaged multistory RC buildings, assistance will be subject to the actual damage, with the limitation of Table 16-11. Here, lowrise buildings are defined as up to ground-plus-three stories or open ground story plus four stories with a building height limitation of 15 m. Above 15 m, it is considered a highrise building.

Table 16-10. Assistance for repair of non-multistoried residential RC structures in Aid Package 4(a)

S.No.	Type of Damage	Assistance
1	More than ½ inch width cracks	Up to Rs. 2,000
2	10% or more damage	Up to Rs. 5,000
3	25% or more damage	Up to Rs. 10,000
4.	50% or more damage	Up to Rs. 20,000

Table 16-11. Assistance for repair of multi storied RC structures in Aid Package 4(a)

S.No.	Type of Damage	Assistance
1	Buildings placed in Category G-2 (a) Low rise buildings (b) High rise buildings	 Up to Rs. 50,000 Up to Rs.100,000
2	Buildings placed in Category G-3 (a) Low rise buildings (b) High rise buildings	 Up to Rs.200,000 Up to Rs.400,000
3	Buildings placed in Category G-4 (a) Low rise buildings (b) High rise buildings	 Up to Rs.400,000 Up to Rs.800,000

Aid Package 4(b)

Meant for load bearing buildings in the urban areas (except the four towns of the Kachchh district). For buildings totally destroyed or pulled down due to safety reasons, assistance will be at the rate of Rs. 2,800 per square meter for up to 50 square meters (that is, up to a total of Rs. 140,000). For completely collapsed huts, the assistance will be up to a maximum of Rs. 2,000. For repair and strengthening, the assistance will be as per Table 16-12.

Table 16-12. Assistance for repair and strengthening of load bearing buildings in Aid Package 4(b)

S.No.	Type of Damage	Assistance
1	More than ½-inch width cracks	Up to Rs. 2,000
2	10% or more damage	Up to Rs. 5,000
3	25% or more damage	Up to Rs. 10,000
4	50% or more damage	Up to Rs. 20,000

Aid Package 5

Applicable to the four towns of Bhuj, Anjar, Bhachau and Rapar in the district of Kachchh. Fairly detailed packages have been evolved for these towns, keeping in view their specific needs. Reconstruction will be a mix of relocation and in-situ reconstruction. Only buildings with a maximum height of up to ground plus two stories will be permitted in these towns. For load bearing construction, the assistance will be as per Table 16-13. For RC buildings completely collapsed, the cash assistance will be at the rate of Rs. 3,000 per square meter for up to 50 m (up to a total of Rs. 150,000). For damaged RC buildings, the assistance is same as in Aid Package 4(a) meant for other urban towns (Table 16-11).

Table 16-13. Financial Assistance for private housing in Bhuj, Anjar, Bhachau and Rapar in Aid Package 5

Damage Category	Assistance
G5	Rs.3000 per m^2 up to a maximum of Rs.150,000
G4	Up to Rs.45,000
G3	Up to Rs.30,000
G2	Up to Rs.15,000
G1	Up to Rs.8,000
Hut fully collapsed	Rs.7,000

About 2,700 civil engineers have been recruited by the GoG to help immediately with the reconstruction project. Most of them have little or no professional experience. It is expected that with some training, these engineers will assist the owners to build or strengthen their homes to be made earthquake resistant. Technical Assistance Cells have been set up in the towns of Bhuj, Anjar, Bhachau and Rapar (Kachchh district) to advise the local government officials and to assist the private owners with structural issues. Structural engineering manpower for these cells has been drawn from professional consulting firms through competition.

CONCLUDING REMARKS

This is one of the two most disastrous earthquakes to have hit India in the past 50 years. The 1993 Latur earthquake in the neighboring state of Maharashtra affected only the rural setting, and the housing stock affected was predominantly in stone masonry. This earthquake added a new dimension of the collapse: damage and vulnerability of the large stock of RC frame buildings built in the metropolitan India, particularly during the last decade. The country was not adequately prepared to undertake the gigantic task of damage assessment, retrofitting and reconstruction for a disaster of this magnitude. The ad hoc improvisations employed for retrofitting such constructions reflect only the urgency of the matter; formal solutions need to be evolved for retrofitting the large stock of RC frame buildings by carefully addressing the technical issues.

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