3.0 INTRODUCTION

In Indian Union, Gujarat has a colorful profile and the age-old cultural heritage of its own. Gujarat is situated on the Western Indian coast between 20.6 & 24.42 degrees north latitude and 68.10 & 74.28 degrees east longitude having a 100 km. long Arabian sea-coastline almost 1/3 of the total sea-coast of India. Its total area consists of 1,96,000 sq. km. (6.10% of that of the Indian Union) from Katchchh in the West to Daman in the South - the hilly tract from Arravlli in the East to the Western hills with lush green forests, thick and thin rivers as well as the plains in the middle. On one hand, Gujarat is blessed with its land, which is fertile, beautiful & prosperous and on the other side due to the peculiar geological profile, almost all types of disasters keep striking Gujarat.

Gujarat being earthquake prone, geological setting is discussed in details in the current chapter. This chapter gives brief history of Gujarat’s multiple disaster hazards scenario with more elaboration on earthquake of 2001. Various damages caused due to Jan 26, 2001 earthquake are highlighted in this present chapter.

3.1 GEOLOGIC SETTING OF THE KACHCHH REGION

The Bhuj earthquake occurred within 400 km from the junction of the Owens fracture zone, Chamam fault, and westernmost Himalayan Frontal Fault System, which collectively form the western boundary of the Indian plate. These structures accommodate about 20 mm per year of relative motion. The Makran subduction zone also terminates against these structures and is a major element of the tectonic framework of the region. In addition, the epicentral region is bounded by the Neogene active Khambat, Surat, and Kachchh grabens (Fig. 3.1).

Major structural features of the Kachchh region include east-west-trending folds and faults\(^{35}\) that deform Mesozoic clastic deposits and Deccan Trap basalts, Tertiary sedimentary units, possible 31 Quaternary terrace surfaces and deposits, and alluvial/intertidal sediments. The principal faults in the region are the east-
trending Katrol Hill fault, Kachchh Mainland fault, Island Belt fault, Allah Bund fault, and Nagar Parker fault.\(^{36}\)

### 3.2 MULTI HAZARD HISTORY OF GUJARAT

The state of Gujarat can be divided into three broad regions based on geographical position and drainage characteristics; (i) south Gujarat, (ii) north & central Gujarat (mainland), and (iii) Kachchh & Saurashtra. Most of the earthquake affected area is located in arid and semi-arid agro-climatic zones where water resources are limited & even scare. The state is exposed to hydro-meteorological and geophysical hazards. Some of the historical hazards are listed in Table 3.1.

#### TABLE 3.1
Gujarat's Multi-hazard Disaster History

<table>
<thead>
<tr>
<th>Disaster Type</th>
<th>Year of Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earthquakes</td>
<td>1668, 1819, 1845, 1846, 1856, 1857, 1869, 1903, 1904, 1938, 1956, 2001</td>
</tr>
</tbody>
</table>

#### 3.2.1 Cyclones

In past 30 years, severe cyclones in 1975, 1976, 1981-83, 1996, 1998 affected Gujarat, killed nearly 3000 people and over 350,000 livestock, and left over millions dwellings partially damaged or totally collapsed. The 1998 cyclone also damaged port facilities, ships and power transmission infrastructure. Cyclone frequency is highest during October and November months. Cyclone damage is caused by wind, heavy rains and associated flooding. In coastal areas, one of the most destructive aspects of cyclones are storm surges-ocean water that is pushed and dragged onto the coast by low pressure and winds, generating storm surges with waves 5 to 10 meters high. Cyclone damage risks are generally higher closed to the coast. The vulnerability of structures can be reduced through cyclone
resistant design measures such as roof straps, storm shutters, and other reinforcements. Loss of lives can be reduced with evacuation planning, cyclone tracking and early warning alerts.

3.2.2 Drought
Substantial portions of Gujarat are arid to semiarid. Historical annual rainfall totals range from 300mm in western part of the state to 1400 mm in the east\(^{(32)}\). Seasonal rainfall amounts vary, depending on the strength and persistence of the seasonal monsoon. The monsoon normally begins in June/July and ends in Sept/Oct. Over past few years data show low rainfall in Gujarat contributing to drought conditions.

3.2.3 Floods
Since 1953, floods have affected an average of over 300,000 hectares annually, with the heaviest flooding occurred in 1988, when some two million hectares were flooded. Annual average damages included 37,000 houses damage, 135 lives lost, and nearly two million people affected. Cattle losses average 13,000 annually. Damage caused by extreme events can be 10 times these averages. Flooding is largely confined to the areas along large rivers such as the Mahi, Narmada and Sabarmati. Flooding occurs seasonally in years when large quantities of rainfall enter a river basin. Disaster prevention largely depends on appropriate land use, timely warning and evacuation.

3.3 - BHUJ EARTHQUAKE 26 JAN, 2001
The Mw7.6 Bhuj earthquake that shook the Indian Province of Gujarat on the morning of January 26, 2001 (Republic Day) is one of the two most deadly earthquakes to strike India in its recorded history. One month after the earthquake official Government of India figures place the death toll at 19,727 and the number of injured at 166,000. Indications are that 600,000 people were left homeless, with 348,000 houses destroyed and an additional 844,000 damaged. The Indian State Department estimates that the earthquake affected, directly or indirectly, 15.9 million people out of a total population of 37.8 million. More than 20,000 cattle are reported killed. In the district of Kachchh over 90% of the deaths and 85% of the asset losses occurred. Government estimates place economic losses at $1.3
billion (Rs. 5850 crore). Other estimates indicate losses may be as high as $5 billion (Rs. 22500 crore).

An informative assessment of damage has been assembled by the various institutes/organizations like Indian Institute of Technology, Kanpur, NICMAR and EERI. Some historical structures that survived the 1819 earthquake have been destroyed in the 2001 earthquake. Despite the complete collapse of some multistory concrete buildings in moderately shaken regions many structures remained intact, indicating that poor quality construction has aggravated the damage during this event. Within one week of the earthquake Ahmedabad police had registered 37 cases of culpable homicide and criminal conspiracy against builders, architects and engineers of buildings that collapsed in the earthquake.

In 1819 a lake was formed south of the Allah Bund that remains a depression (Lake Sindri) that is flooded during the summer monsoon. The region has experienced above normal levels of micro-seismicity throughout the past 200 years, and probably for many millennia. Damaging earthquakes occurred in 1668, 1819, 1845, 1846, 1856, 1857, 1869 1903, 1904 and 1956 in the same general region as the 1819 and 2001 earthquakes. Vertical deformation in 1819 reached 6.2m and in 1956, 1m. The fault that slipped may have been the southern boundary fault system to the Kachchh Graben with a strike N30E rather than N30W as depicted in Figure 3.1.

The present work is focused on the damage quantification caused due to an earthquake. In the following paras study of different types of damages occurred to various buildings due to Jan 26, 2001 earthquake are explained.

### 3.4 TYPES OF OBSERVED DAMAGES IN KACHCHAR

Various structures, monuments and buildings of the Kachchh, suffered from structural damages. Some of these damages are described below. It is noted, many construction in that region is constructed by unqualified contractors by using rules of thumb for structural work as well as for construction, which is called as Non-engineered construction.
3.4.1 Non-Engineered Rubble Masonry Buildings

Many buildings in Kachchh of up to 2 storeys in height are made of random rubble masonry construction. The 26 January 2001 earthquake caused massive damage to these buildings. A great many of them partially or completely collapsed (damage category 5 as mentioned in chapter two), especially close to the epicentre in Bhuj, Anjar, Bachau and Sukhpur, where the destruction was almost total. Towns and villages that are away from the epicentre of the earthquake were less affected but only in the sense that total collapse was not as widespread. For example, near the villages of Kera or Naranpur buildings of this nature were still standing (damage category 4) with sometimes only partial collapse.

During the earthquake, many buildings easily separated at corners and T-junctions resulting in walls overturning and roofs collapsing, which killed thousands of people. This was because the random rubble walls were made of uneven stone and the stones were laid on either weak soil or mortar bedding. Under the heavy seismic shaking, the tensile strength of the mortar (and rubble) was easily exceeded, and walls bulged or totally collapsed. In addition many of these buildings had timber or heavy stone slab roofs that were not properly tied to the top of the walls and the walls then came apart causing the roof to cave in. These damages are grouped under 4th damage category.

Even single storey buildings suffered severe damage and/or partial or complete collapse. Figure 3.2 and 3.3 shows some of the failure of these buildings under damage category 5. As Kachchh is in the highest seismic zones, new buildings should not be made from random masonry walls, if affordable, as they are incapable of resisting the severe shaking.

3.4.2 Non-Engineered Cut-Stone Masonry Wall Buildings

Generally, cut-stone and concrete block-work buildings are built with more care and attention than rubble masonry structures but again were not seismically designed. Older buildings had timber floors and roof, while newer construction have concrete floors with a flat concrete roof or a clay tiled timber roof. Many were damaged but did not collapse. Damage varied from slight to heavy as per damage category 3.
The masonry buildings which performed the best have the following features in common:

- Cut-stones were bedded in cement mortar
- Roofs were properly fixed to the top of the walls.
- Window openings were sensibly sized in relation to the total wall length;
- Buildings were symmetrical with no concentrated masses;
- Many had cross walls at sensible spacing, although it was unclear whether they were adequately tied at T and L junctions;
- Foundations were typically founded at 0.5 to 1.0m depth, probably on firm to medium dense soils or rock.

i. Old Masonry Building Built with Thick Cut-stones
An old government building (predating 1900's) made with solid cut stone masonry walls is shown in Figure 3.5. This building received slight to moderate damage (damage category 2) although it is in the centre of Bhuj and all around, rubble buildings have totally collapsed. The floors and roof are of timber and an adjacent similar building had cut-stone walls which were at least 0.5m thick. The upper storey wall is seen to be damaged at the edges by bending cracks caused by out-of-plane shear forces. Untied architectural stonework has also fallen off at roof level, as might be expected from severe shaking. The heavy wall units and regular stone blocks prevented collapse of these old buildings.

ii. Window Openings
Figure 3.6 shows a two-storey modern cut-store wall building near Bhuj, in town called Mirzapur. The building has cut-stone walls about 0.225 to 0.3m thick and has a concrete floor and a pitched timber roof. The window openings are not close to the edge and are also sensibly spaced. This is probably one of the main reasons why it survived with so little damage. Even so some vertical bending cracking has happened near to the corners, again due to out of plane shear forces.
III. Peripheral Seismic Bands or Ties

Seismic bands or ties greatly increase the strength of buildings in earthquakes. The railway lookout building in Figure 3.7 is made with random masonry, is well-constructed and is bonded with cement mortar and suffered very little damage (damage category 1). What sets this building apart from others that collapsed nearby is that it has been designed with strong reinforced concrete seismic bands at lintel and sill level, which completely tie the four walls. There is also a flat concrete roof. The seismic shear force is resisted by the lintel and sill bands, and has clearly strengthened the building against repeated shaking from an earthquake which would make lesser buildings collapse.

3.4.3 Non-Engineered Reinforced Concrete Buildings

In the last 10 to 15 years reinforced concrete frame structures have become a common construction feature of domestic buildings in Kachchh. These are usually frames of concrete column and slab construction with either a flat concrete roof or a pitched timber roof to keep the interior of the building cool in the summer. They are usually up to 2 to 3 storeys in height. These buildings were designed to support the vertical weight of the structure. The majority were damaged in the earthquake because they were not designed to resist horizontal forces caused by seismic loading.

i. Building Configuration and Soft Storey Collapse

Some domestic reinforced concrete buildings had large internal openings or unsymmetrical masses at first or ground floor level. This caused severe structural damage and even collapse. Figure 3.8a shows a building, which collapsed (category 5) because part of the floor area was converted to an opening for car parking. The building was subjected to torsion about its centre of rigidity and failed because of soft storey behaviour with large deformations and rotations concentrated at the top of the columns.

The inset shows large deformations were concentrated at column heads, which caused many soft storey failures, as per picture. Buildings if designed with uniform deflections as per left diagram of insert would have survived without collapse.
Figure 3.9 shows a building where the owner had a middle floor supported on columns with large internal open spaces, and hardly any masonry infill walls. Under seismic loading, large deformations occurred at the top and bottom of the columns and a soft storey collapse occurred, the upper floor storey falling onto the first storey. This shows that soft storey collapses do not always occur at ground floor.

ii. Non-Engineered Infill Walls Acting as Shear Walls
Many buildings were prevented from collapse by the presence of "non-structural" infill wall panels which acted as shear walls despite not being designed for this purpose. No buildings were designed as moment resisting concrete frames to resist cyclic shear and bending moments at column and beam connections.

Figure 3.10 shows the effectiveness of shear walls in preventing an RC framed building from collapse. This building experienced severe shaking causing moderate to heavy damage (category 3) to the infill panels, but this prevented column failure. Many infill panels in these types of buildings will need to be restored following the earthquake. It should be noted that this wall was effective despite being compromised by the presence of a door opening.

iii. Crushing of Column Head and Bases
When masonry infill walls were ineffective because of large openings, column heads were subjected to large vertical and lateral seismic forces. The heavy eccentric compressive stresses crushed column heads and large shear deformations caused concrete to spall away from the main bars because of links being too far apart. The extent of damage to the column heads often depended on how well the infill wall panels were bonded to the columns. Figures 3.12 and 3.13 give examples of this.

Some common problems, which resulted in severe damage to the column heads or bases, were from poor detailing as follows:
- Drain pipes and other services placed inside columns, caused severe weakening of the columns making it less resistant to lateral loading;
- Shear link spacing was too large (typically 200-300mm), thus not providing adequate confinement to the main bars, causing concrete to fall out;
- Links were not bent backwards into the columns so they easily separated, again letting concrete out of the main bars;
- Very small links (6mm diameter) were used;
- Main bars were not bent back into the floor or ground beams so that reversal of shear loads could not be resisted by the beam and column connections. Many failures occurred at beam/column junctions, see Figure 3.14.

div. Canopy Structures
Several modern buildings had a single storey canopy with a flat roof supported by columns at one end and beams running into the main structural frame at the other end. These suffered varying degrees of damage depending on how slim the columns were, see Fig 3.15.

3.5 DAMAGE ASSESSMENT
A survey has been conducted for earthquake damage assessment with a team of 110 post graduate diploma students guided by 10 faculty members as described earlier. Details of damages recorded in the Damage Assessment sheets are summarised in Table 3.2, 3.3 and 3.4. In Ahmedabad as many as 171 high-rise buildings collapsed completely. These damages are summarised as below:
- Total Destroyed Houses : 228906
- Total Damaged Houses : 397538
- Total Human Deaths : 16435
- Total Seriously Injured : 20717
- Injured Persons : 68478
- Cattle Dead : 12250

3.5.1 Extent of Damage
Damages reported after a year by Ministry of Agriculture, Govt. of India, N. Delhi through weekly situation Report No. 74 dated 20, March 2001 are as under:
- 7904 villages affected in 182 talukas in 21 districts.
- 1.97 crore affected out of 3.78 crore population.
Human lives lost: 19145, Persons Injured: 1.66 lakh
Cattle deaths reported at 20712.
Houses Destroyed - 1.65 lakh (Pucca), 1.60 lakh (Kachcha) & 0.16 lakh (huts)
Houses Damaged - 4.50 lakh (Pucca), 3.09 lakh (Kachcha) & 0.31 lakh (huts)
Financial Loss - Rs. 1923.36 crore (Pucca) Rs. 619.26 crore (Kachcha) and Rs. 61.82 crore (Huts)

Above damage data are collected by NICMAR and report published by the Govt. There are differences in the numbers due to: (i) non-standardisations of assessment formats used in the country, (ii) in the event of disaster of this magnitude it is practically difficult to count each and (iii) every number and use of different attributes during assessment.
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TABLE 3.3
Village-wise Damage Summary Report

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<thead>
<tr>
<th>Sr. No.</th>
<th>Name of Village</th>
<th>Existing House Nos. (Approx.)</th>
<th>No. of Houses Surveyed</th>
<th>Total BUA sft.</th>
<th>Cost of Damage in Rs.</th>
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TABLE 3.4
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Present work is limited to only estimation of building damages. These damages directly affect people and play very critical role in organising short term disaster management. Damages caused to infrastructures, facilities and services are also important, but affected people and their shelter being of prime importance, in the present work only estimation of building damages are covered to develop the model. However damages caused to various infrastructures are described in short in the following paras.
3.6 DAMAGES TO INFRASTRUCTURES

The Kuchchh region has 20 small to medium size dams of 10 to 25m high and 165 minor irrigation schemes. There are embankment dams (minor dams 3.15 m height) with chute spillways or ground bar waste weir. Nine dams have been reported to be very severely damaged. Most of the damaged dams are located in Kachchh district and lie within a radius of about 80-km from the epicenter. The major damages have occurred in dams located west of Bhuj city. Earthen dams such as Rudramata, Kasawati, Fatehgarh, Suvi, Tappar, Kaila, Chang and Shivalakha in the Kuchchh were damaged severely.

Two bridges in Surajbari located at 43 km to the southeast of the epicenter across the little Rann of Kuchchh, on the Kandla road were damaged by the earthquake. These bridges, e.g. the Old Bridge and the New Bridge provide a vital link between the entire Kuchchh district and the western part of India. Most of the retaining walls, wing walls, bridge abutments and soil embankments located in Kachchh area are damaged or have failed either due to liquefaction of foundation soils and / or inadequate slopes. On the road from Anjar to Rapar, many deep cuts and lateral spreading have been observed in road embankments of only 1 to 2 m height. This stretch lies in an area that sustained intensity of shaking X on the MSK scale. Similarly at several places, the road surface was cracked. Specifically, north of Rajkot on the way to Bhuj shows that one side of the road moved laterally by about 4 cm and additional cracks developed terminating on that lateral displacement.

Liquefaction, sand and salt boils were very extensive and widespread due to the Gujarat earthquake and some of the such areas were along the road side drive to Bhuj to the Rann of Kuchchh, adjacent areas to Lodai, Manfara, Bachau, Choberi, Navalakhi port, Kandla port and the reservoirs of Kaswati, Fatehgarh, Suvi, Tappar and Chang dams.

Extensive damage was caused to water supply, electricity and telecommunication lines. The power supply was amongst the first utilities to go out of commission. The immediate loss of 3000 Mw in power grid and tripping of 220 Kv in Kachchh resulted in total blackout for 8 to 48 hours. The earthquake left almost 45 substations of
Kachchh and 255 feeders adversely affected. 9 towns and 925 villages were completely blacked out. The water supply in 10 towns of Kachchh and 8 other towns of Rajkot, Jamnagar, Ahmedabad and Surendranagar was severely affected.

<table>
<thead>
<tr>
<th>Affected districts</th>
<th>No. of damaged telephone exchanges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kachchh</td>
<td>47</td>
</tr>
<tr>
<td>Rajkot</td>
<td>25</td>
</tr>
<tr>
<td>Jamnagar</td>
<td>4</td>
</tr>
<tr>
<td>Surendranagar</td>
<td>3</td>
</tr>
</tbody>
</table>

This earthquake was a major set back for the industries as almost 10000 small and medium industrial units went out of production. The famous handicraft of Kachchh district suffered enormously and almost 50000 artisans lost their livelihood. The tiles and ceramic units in the district underwent severe losses.

Education suffered a major set back in the area as almost 1500 schools were completely destroyed.

The earthquake has completely destroyed two District hospitals, 20 Community Health Centers (CHC), 50 Public Health Centers (PHC) and 300 sub-centres. Many other health facilities have sustained partial damage and may have been structurally weakened. A preliminary assessment of the damage was estimated to be Rs 1705 million.

There has also been substantial damage to the water supply with 319 tube wells damaged (274 in Kachchh) affecting 18 towns and 1340 villages. About 50% of the pipeline network in Banaskantha, Jamnager, Kachchh and Rajkot was damaged. This damage has severely affected access to clean water and health care.

1,774 Child Development Centers (CDC) managed by Anganwadi workers were destroyed.
3.7 FINANCIAL ASSISTANCE UNDER REHABILITATION PROGRAMME

Various damages, losses, causalities, human injuries, cattle/animal deaths etc. due to a calamity is required to put together in single figure to project the size of the disaster. Money is taken as a base to convert all the above said losses caused in a single unit. Rehabilitation packages announced by the Gujarat State Disaster Management Authority (GSDMA) based on the recommendations of the Task force are taken as a base in the present work to convert all the losses in a money scale.

3.7.1 Relief at Glance

Compensations provided under various financial packages announced by Govt. of Gujarat are summarized as under:

i. Lives Losses/Injury
   a. Death Relief : Rs. 1 lakh per person.
   b. Disability (40% injury) : Rs. 30,000 per person.
   c. Major injury : Rs. 10,000 per person.
   d. Minor injury : Rs. 5,000 per person.
   e. Cattle Death : Rs. 3000.

ii. Houses Damages
   Pucca Houses completely destroyed : Rs. 1 lakh
   Huts completely destroyed : Rs. 15,000
   Relief for the partially damaged houses, as declared in package No. 2 (Revenue Department resolution No.XLS-162001-207-(4)-S.3 dated Feb 2001.) is given below.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Category</th>
<th>Assistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>If there are crack/cracks of atleast ½ inch width.</td>
<td>Upto Rs. 3,000/-</td>
</tr>
<tr>
<td>2.</td>
<td>Damage upto 10 %</td>
<td>Upto Rs. 7,000/-</td>
</tr>
<tr>
<td>3.</td>
<td>Damage upto 25 %</td>
<td>Upto Rs. 15,000/-</td>
</tr>
<tr>
<td>4.</td>
<td>Damage upto 50 %</td>
<td>Upto Rs. 30,000/-</td>
</tr>
</tbody>
</table>

The scale of assistance for the partially damaged houses will be as under:-

The assistance will be available to owner/actual possessor of the property. Apart from above assistance, if any affected beneficiary intends to avail the facility of loan, the Government will try to arrange for loan upto Rs.1.00,000 from the Bank or from...
any other Financial Institutions at the interest rate to be fixed by such institutions. The Government will not provide any interest subsidy. The beneficiary has to clearly indicate the requirement of loan amount during the survey.

3.7.2 Money Estimate of Damage and Loss

It is estimated the total losses due to collapse of structures and utilities at Rs. 2,08,750 million with the following breakup:

- Industrial and Commercial buildings : 80,000 Rs.million
- Houses and Belongings of dwellers : 1,10,000 Rs.million
- Public Buildings : 18,750 Rs.million

Estimate of indirect loss released by the Gujarat State Chamber of Commerce put the figure at Rs. 2,50,000 million with following details:

i. Current Account (Rs. Million= m)
   - Loss to Kandla port due to absence of workers : Rs. 15m/day
   - Production losses in factories : Rs. 6-10 Tm/day

ii. Capital Account (Rs. Thousand Million= Tm)
   - Manufacturing Industry : Rs 70 Tm
   - Fall in collection of sale tax : Rs. 5 Tm/day
   - Fall in Income Tax collection : Rs. 1.5 – 2 Tm/day

3.7.3 Monetary losses are summarized as:

- Personal Properties : Rs. 387 crore
- Household Properties : Rs. 11195 crore
- Public Utilities : Rs. 600 crore
- Public Infrastructure & Amenities : Rs. 1080 crore
- Industrial establishment : Rs. 5000 crore
- Commercial establishment : Rs. 3000 crore

Total estimated loss of damage: Rs. 21262 crore

This damage assessment helps in deciding the level of disaster and appropriate arrangement required to combat the effect of the disaster to bring back the normalcy.
3.8 CONCLUDING REMARKS

Thus in the present chapter various damages occurred to the buildings along with compensation packages offered during Bhuj earthquake disaster are highlighted. Present study is an effort to predict the approximate quantum of damages due to earthquakes. The Vulnerability Assessment Model to predict the quantum of damages that could occur due to future earthquakes is presented in the next chapter.
Fig. No 3.1 – Tectonic Map of Gujarat
Study of Gujarat Earthquake Damages: Chapter III

Figure 3.2 - Collapse of Random Masonry Building in Manukawa

Figure 3.3 - Partial Collapse of Gable Wall for a Single Storey Random Masonry Wall in Kera
Figure 3.4 – Heavily Damaged Single Storey Rubble Masonry Wall with Concrete Roof in Manukawa & Sukhpur.

Note: Walls survived due to diaphragm action from roof. Cantilever beams embedded in walls also helped this.

Figure 3.5 Cut-Stone Building in Bhuj
Figure 3.6 Modern cut-stone masonry building in Mirzapur

Figure 3.7: Strengthening of Buildings by Use of Seismic Bands
Figure 3.8a - Typical soft storey and torsion collapse in Bhuj

Figure 3.9 – Soft Storey Second Floor Collapse in Sukhpur
Figure 3.10 Infill Panels to an Reinforced Concrete Frame Building acting as Non-structural Shear Walls, Provided Stability to the Overall Frame – Bharasar

Figure 3.11 Infill Panels again Prevented Collapse of this Structure although all the Roof Tiles Fell Off - Mirzapur.
Figure 3.12: Heavy compressive stresses with large deformations causing total destruction of column head with heavily bent main bars. Concrete not contained by links because they were to far apart.

Figure 3.13 A column that survived with minimal distortion as infill walls performed well and repairs being carried out to damaged column head showing minimal distortion to main bars (right)
Figure 3.14: Separation of ground beam and column junctions caused by concrete crushing in Sukhpur. Damage made worse by the weakening presence of a plastic pipe within the column.

Figure 3.15: Collapse of a canopy structure due to column failure.