PRELIMINARY OBSERVATIONS ON DAMAGE TO BUILDINGS IN GUJARAT (WESTERN INDIA) EARTHQUAKE OF JANUARY 26, 2001

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ABSTRACT: About three weeks after the Gujarat earthquake, the authors were deployed by the Department of Architecture and Environment, Akita Prefectural University, to undertake a preliminary assessment of the nature of damage to buildings in some of the affected areas of Gujarat. The trip was organized over a very short period and without any detailed planning and without benefit of adequate prior information about field conditions in the earthquake aftermath. Actually, primary objective was to gather the basic necessary factual information about the actual situation in the affected region, based on which other institutions in Japan may be able to organize teams of engineers for more detailed investigation. Further, considering the relief work that was expected to be in full force, the field observations were kept as unintrusive as possible. This report attempts to summarize some preliminary observations based on the field trip by the authors, and mostly consists of photographs of damaged buildings.

KEYWORDS: Gujarat (India) earthquake, Earthquake damage, Field observation, Damage distribution, Earthquake zoning, Design standard, Reinforced concrete buildings

INTRODUCTION

The Kachchh region of Gujarat, India was jolted by a massive earthquake at 8:46 (local time) of January 26, 2001. The earthquake was reported to have a magnitude of 7.7 and caused extensive damage, destruction and loss of lives over a wide region in the state of Gujarat, affecting about 16 million people. The impact of the main shock was felt as far away as Calcutta and Kathmandu, Nepal. The Ministry of Agriculture, Government of India (http://ndmindia.nic.in/eq2001/eq2001.html), reports a death toll of over 20,000, number of injured of 167,000 and estimated economic loss due to the quake of about 4.5 billion. Destruction of about 1000 school buildings and several hospitals have further added to the constraints in relief operation and social rehabilitation. The earthquake caused complete devastation and extensive destruction of several towns in the Kachchh region of Gujarat, including Bhachau, Anjar, Bhuj, Adipur and Gandhidham.

Figure 1 shows the different districts of the state of Gujarat, including the heavily affected Kachchh region. The figures in the parenthesis in Figure 1 show the death toll due to the earthquake in different districts. About 18,416 of the total reported deaths of over 20,000 was concentrated in the Kachchh district, with headquarter at Bhuj. The second highest number at is in Ahmedabad, which is about 300km to the east from Bhuj.

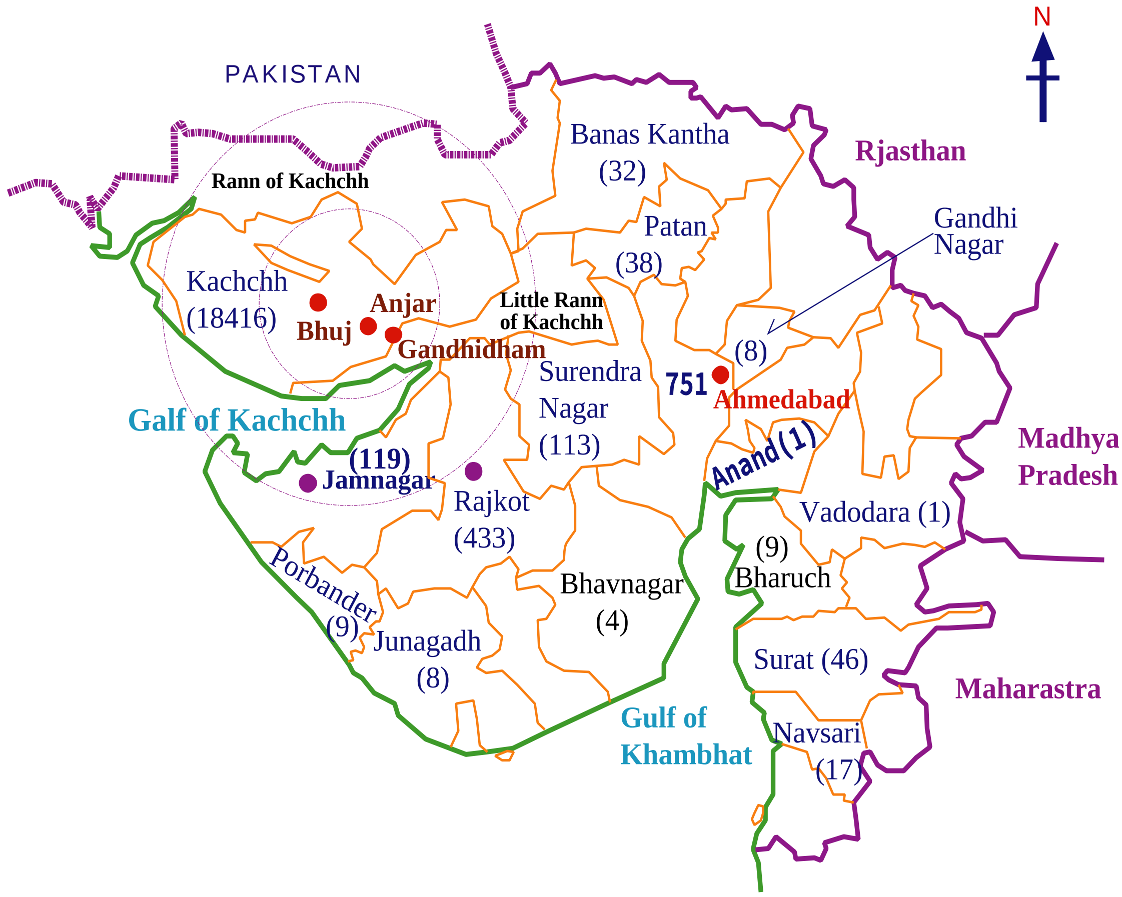

Figure 1. Epicentral region and surrounding districts of Gujarat. The figures in the parenthesis show the casualties in different districts due to the earthquake of January 26, 2001.

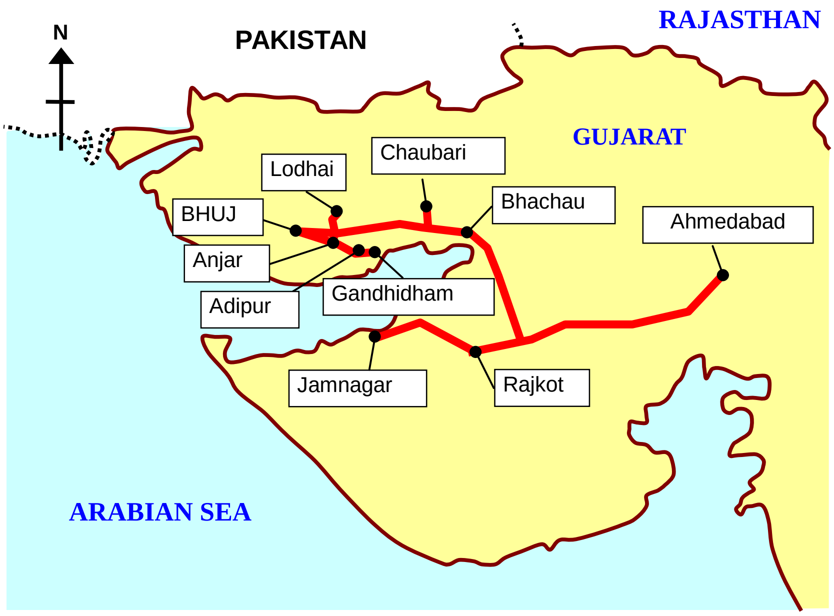

Figure 2. The route traversed and the townships visited during the field trip to Gujarat, India byt the authors

The route taken by the authors during the field trip is depicted in Figure 2. After flying in from Bombay, two days were spent in Ahmedabad, observing some of the multistory apartment buildings damaged by the quake and planning for the travel to Kachchh region by road. Lack of adequate information meant that details of the planned visit were very sketchy before leaving Japan. Actually, the trip was organized over a very short period and without the benefit of adequate prior information about field conditions. Rather than undertaking a detailed observational investigation, the primary objective was to gather the basic necessary factual information about the actual situation in the affected region, based on which other institutions in Japan may be able to organize teams of engineers for more detailed investigation. In addition, considering the relief work in progress, the field observations were to be as unintrusive as possible.

SEISMICITY AND TECTONICS OF THE REGION

Major destructive earthquakes have occurred in South Asia historically, as shown in Figure 3. These include some of the very destructive events such as the 1905 Kangra earthquake, 1934 Indo-Nepal Border earthquake and 1935 Quetta earthquake. The general nature of the plate tectonics of the Himalayan region, accompanying the overall northward movement of the Indian subcontinent and its collision with the Asian plate, has been fairly well established. However, the actual local tectonic settings resulting in the individual events have never been studied in detail, primarily due to the lack of proper recording system. Consequently, it is no exception that the causative tectonic setting of the Gujarat earthquake is far clear, and its source mechanism may be never fully understood. Figure 3 shows the epicenter location of the events of magnitude greater than 6 in South Asia.

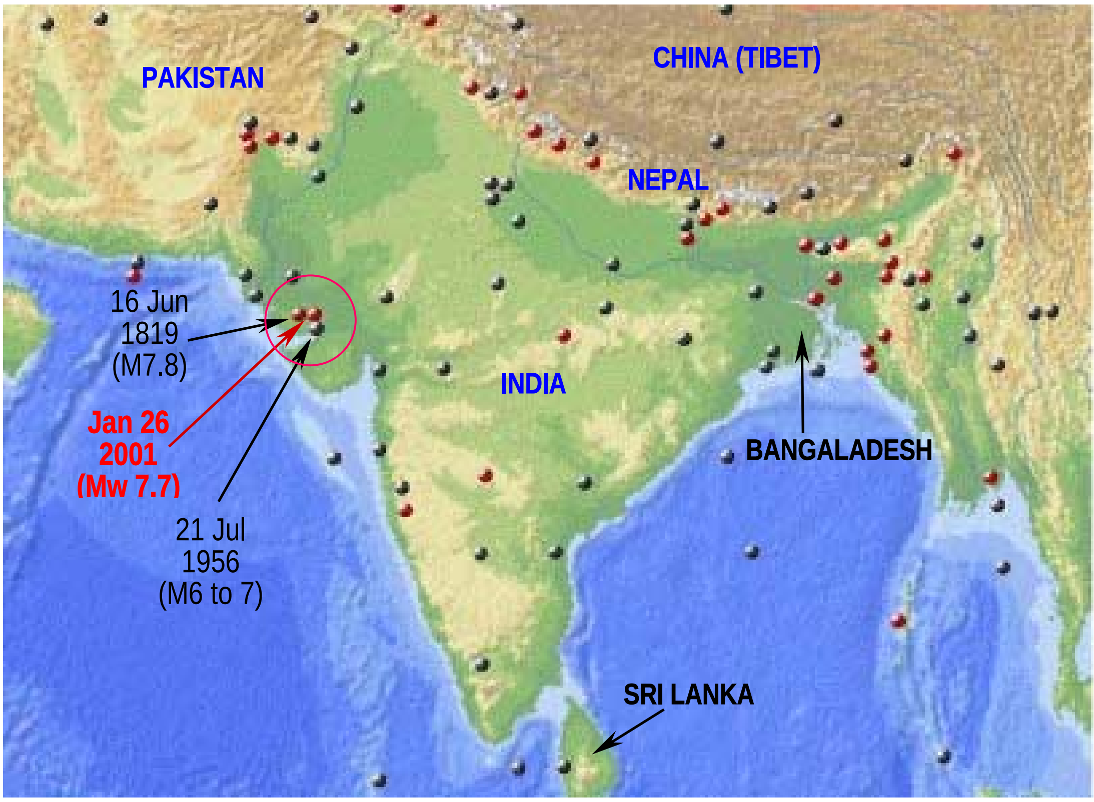

Figure 3. The Gujarat earthquake of January 26, 2001 in relation to some of the major historical earthquakes in South Asia. Only earthquakes of magnitude 6 and higher are shown. (Source: Amateur Seismic Center, *www.goecities.com/stacertin/greatquakes.html*)

The nature of seismicity depicted in Figure 3 by the location of epicenters of major historical earthquakes provides ample evidence of the risk involved in the Kachchh region (the circled area). Prior events in the Kachchh region with magnitudes estimated to be comparable to the 26 January 2001 event include the 16 June 1819 earthquake and the 21 July 1956 earthquake, as shown in Figure 3. Overall, it seems to indicate a return period of the order of 50 years for this scale of earthquake events in the Kachchh region affected by the recent earthquake. It should, however, be noted that the locations of earthquake epicenters shown in Figure 3 are only approximate and the information about past earthquakes is limited and often sketchy.

The seismic zoning map of India shown in Figure 4 seems to reflect the general nature of seismicity depicted in Figure 3. The zoning system in India consists of five zones denoted as I to V, with zone V depicting the region with highest earthquake risk. It may be noted that the Kachchh region is assigned as zone V, together with parts of northern and north-eastern regions lying closer to the Himalayan Frontal Fault System (HFFS) that delineates part of the intercontinental collision between Indo-Australian plate and the Eurasian plate, resulting in the formation of Himalayan mountain range. In short, it is evident that the seismicity of Kachchh region had been recognized well in the academic and engineering circles, although it is not clear if the population living in the area were aware about it.

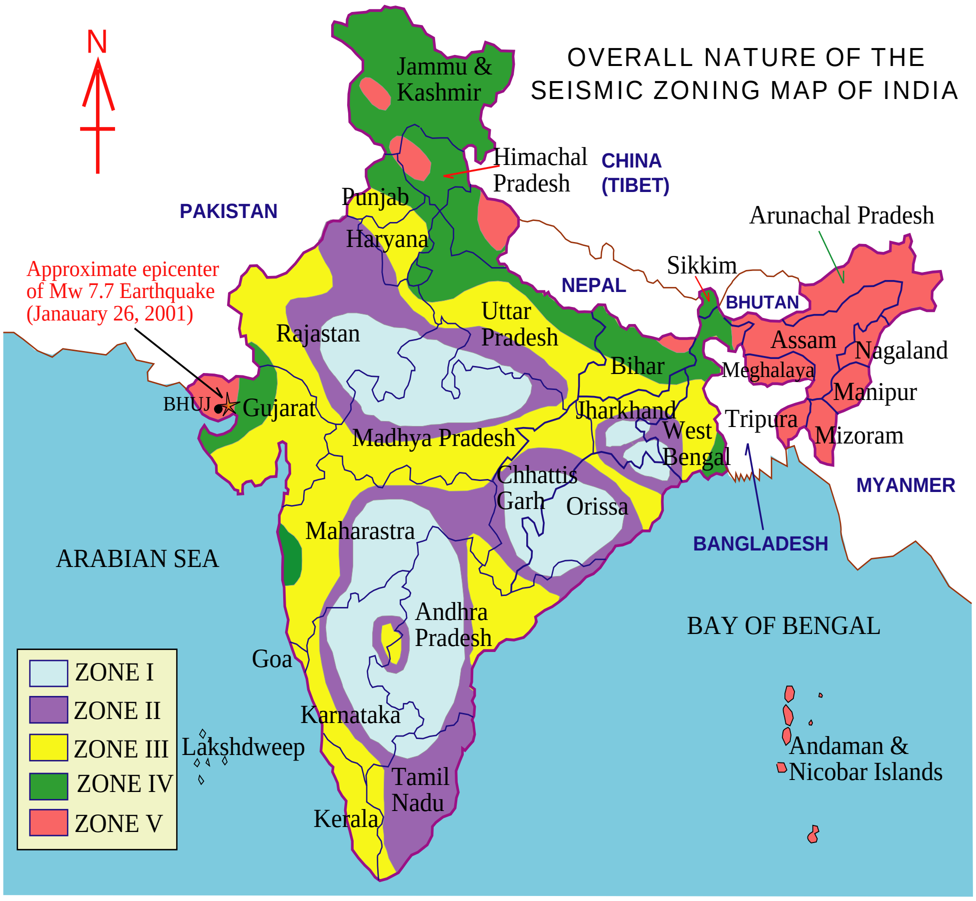

Figure 4. Nature of seismic zoning map of India, which seems to reflect the seismicity depicted in Figure 3.

As mentioned above, the tectonic setting of the Kachchh region resulting in the January 26, 2001 event is not understood very well and the details about source mechanism of the event are still unclear. Based on the teleseismic data, USGS (http://neic.usgs.gov/neis/bulletin/mag7.html) has reported the epicenter coordinates to be 23.33°N and 70.32°E and a hypocentral depth of 22 km. The distribution of the different active faults in the Kachchh region are shown in Figure 5, where the locations of the epicenters of past earthquakes are also shown. The seismic belt of the Kachchh region seems to extend over a range of about 150km in the north-south direction, enclosed by the Nagar Parker Fault in the north and the Kathiwar uplift zone in the south. Other major faults mostly tending in the east-west direction include Allah Bund Fault, Island Belt Fault, Banni Fault, Kachchh Mainland Fault (KMF) and Katrol Hill Fault. Various past earthquake events of magnitude greater than 5 may be noted in relation to the 26 January 2001 event, which is said to have mobilized a section of the Kachchh Mainland Fault (KMF) stretching between Lodhai and Chaubari, as illustrated in Figure 5.

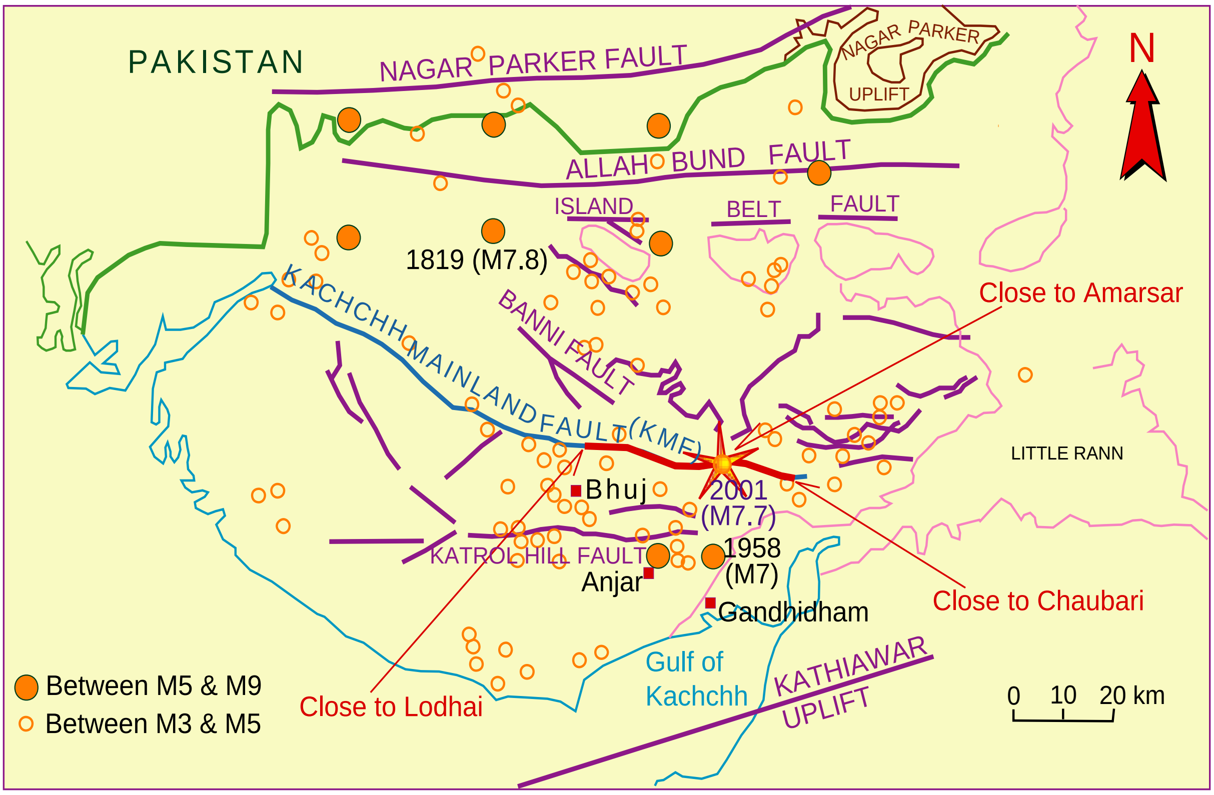

Figure 5. Different active faults already identified in the Kachchh region of Gujarat, India and the approximate epicenter locations of earthquakes in the region. The probable location of epicenter of the 26 January 2001 earthquake occurring in the Kachchh Mainland Fault (KMF) is said to be near the Village of Amarsar. (Map prepared based on the news item of February 20, 2001 in the Times of India, Ahmedabad)

The actual location of the epicenter of this event is reported to be near the village of Amarsar, about 30km east of Bhuj. It seems there were no strong motion recorders installed within the Kachchh seismic zone delineated in Figure 5, the closest recording being from Ahmedabad, over 200km from the epicenter. The peak ground acceleration recorded in Ahmedabad is reported to be 0.11g, but the details about the placement of recording station and the local site condition and geology of the site is not clear. In spite of the large magnitude and relatively shallow depth of hypocenter, it seems no evidence of major surface rupture accompanying the fault movement was identified. However, ground deformation within the alluvial deposit over a stretch of KMF, between Lodhai in the west and Chaubari in the east as shown in Figure 5, has been commonly observed and reported. The deformation is manifested in the form of extensional cracking and bulging due to compression, mostly stretching in the east west direction. In some locations, the ground deformations were also associated with sand boils accompanying expulsion of salt water, as shown in Figure 6 to 9.

Figure 6. Extensional deformation over alluvial deposit observed near Lodhai. The inset shows the close-up view from within the cracks, where the evidence of salt-water expulsion may be noted from the salt deposit after evaporation.

Figure 7. Sand boil and expulsion of salt water to the surface observed near Lodhai at a location to the east of that shown in Figure 6. Water was still oozing out when the authors visited the site on February 23, 2001.

Figure 8. Extensional ground cracks observed near Chaubari stretching over barren land and corn fields

Figure 9. Extensional ground cracks crossing a small hut located in between the barren land and the corn field shown in Figure 8, with the corn field to the west.

DAMAGE TO BUILDING STRUCTURES

This being a preliminary report, only the photographs with accompanying captions are given in this section. The photographs are grouped based on the locations and attempt is made to provide captions to some detail.

Ahmedabad

Source: http://gujaratearthquake.homestead.com/

Figure 10. General and close-up view of the damaged multistory building (Manasi complex) in Ahmedabad soon after the earthquake. Photograph from the web page shown above.

Figure 11. General and close-up view of Manasi complex when the authors visited on February 20, 2001.

Figure 12. The rubble of concrete and reinforcement from the collapsed portion of the Manasi complex dumped across the street nearby. Most of the buildings seen in the background seem to have little if any structural damage.

Figure 13. Close-up view of the rubble from Manasi complex, showing the nature of reinforcement placement and the quality of concrete utilized in columns in the collapsed portion.

Figure 14. Wreckage of collapsed building and crushed vehicles parked in the open ground floor, near Maninagar station, south east of Ahmedabad. The adjacent building with open first floor parking space sustained some damage mostly due to the impact of collapsed building.

Figure 15. Wreckage of collapsed elementary school building in Khokhra, north of Maninagar, Ahmedabad. The adjacent 4 story Cadila health center building and other surrounding buildings appeared to suffer minimum if any damage.

Jamnagar

Figure 16. Hotel Aram in Jamnagar, consisting of a stucco building dating back to the times of British India. The building looked intact from distance and it was in business. However, looking closer it was found that the building had many cracks and owner some repair of the damage was undergoing as the hotel was running.

Figure 17. Closer look at the cracks on the exterior walls of Hotel Aram building. The cracks and damages on interior walls may have been more severe at sections the owner had already undertaken repairs and covered with cement mortar.

On the Way to Bhuj

Figure 18. Damage seen from the road at Samakhial, on the way to Bhuj from Rajkot on Feb 22, 2001. The location is about 90km east of Bhuj and about 20km east of Bhachau.

Figure 19. A new housing complex just ready for occupation, consisting of load bearing brick wall structures. The location is between Samakhial and Bhachau, about 80km east of Bhuj.

Figure 20. Severely damaged but still standing two housing unit block of the new housing complex shown in Figure 19. The small housing units are complete with parking lots, but the structural design does not seem to have considered seismic aspects. The bed seen outside is for the people guarding the property.

Figure 21. Completely collapsed block of two housing units similar to that shown in Figure 21. It had collapsed completely with large southward movement, which may be due to the presence of stronger north south motion this earthquake.

Figure 22. Collapsed office building of gasoline station near Bhachau. The gas station was in operation.

Figure 23. Closer view of the collapsed building of the gasoline station near Bhachau.

Figure 24. Collapse of the incomplete KC Polytec Ltd. factory building between Dagala and Madhapur, about 20km east of Bhuj. The building had collapsed with large southward movement.

Figure 25. Close-up view of the top of concrete column supporting the factory building of Figure 24, showing the reinforcement details and concrete quality, and a substantial southward movement. The large southward movement may be due to stronger north south motion.

Bhuj City Area

Figure 26. Buildings in different state of collapse and damage with wreckage dump in the foreground.

Figure 27. Partly collapsed massive concrete framed building structure with infill brick masonry walls.

Figure 28. Group of damaged, tilted & partly toppled apparently relatively new apartment blocks in the central part of Bhuj. Damages to some of the buildings in the group seemed to be repairable.

Figure 29. Close-up view of Figure 28 showing tilted buildings and toppled overhead water tank.

Figure 30. Apartment block consisting of reinforced concrete structure, severely tilted due to collapse of the first story. Apparently, the collapse resulted due to soft ground floor.

Figure 31. Housing complex with two-storied load bearing brick masonry structures in Bhuj, apparently still occupied after the earthquake.

Figure 32. Closer view of the brick masonry housing units seen in Figure 31. Although severely cracked, the brick masonry housing units seem to have been kept from complete collapse.

Figure 33. View from the lakeside in Bhuj facing south. Although it was not possible to inspect all the buildings closely, some of the structures in the background seemed to have resisted the earthquake shaking without large scale damage.

Figure 34. View from the lakeside facing west. Again, some of the building structures in the background seemed to have resisted the shaking without large scale damage. To the right can be seen the historical site of holy burial ground for kings and queens.

Figure 35. Closer view of the damage to holy burial ground for kings and queens from early days, allegedly from over 200 years ago.

Figure 36. Overall view of the collapsed first story and tilting of relatively new concrete buildings with open space in the ground floor for shops and the like, crearing a soft ground floor.

Figure 37. Closer view of collapsed ground floor with store front sign boards sitting on the floor.

Figure 38. Close-up view of the nature of failure in the ground floor reinforced concrete columns together with a magnified view of column reinforcement with deficient lateral ties for confinement. Also the presence of aggregate in the concrete was difficult to discern.

City of Anjar

Figure 39. Badly cracked but standing pigeon house in the midst of total devastation of human habitation all around in Anjar. The supporting structure of pigeon house consists of masonry in mud mortar.

Figure 40. Partly collapsed and badly damaged new reinforced concrete building in Anjar just opposite (to the north) of the pigeon house shown in Figure 39. It seemed the building was designed to be more or less symmetrical on both sides of the stairs at the central part.

Adipur, on the Way to Gandhidham from Anjar

Figure 40. Damage and disruption at the polytechnic in Adipur where the girl's wing survived with severe cracking, but the collapse of boy's hostel resulted in a very large casualty.

Figure 41. Apparently undamaged residential building adjacent to the community polytechnic, where the repair of the collapsed boundary wall (inset) was in progress to the left of entrance gate.

Figure 42. Frontage and the inside of Rotary institute for speech and hearing handicapped. The institute was closed after the earthquake, but the director who was kind enough to guide the authors the inside was planning repairs. Mostly, the damage seemed repairable.

The City of Gandhidham

Figure 43. Demolition & removal of wreckage (left) and manual demolition in progress of a damaged hospital building with mid-floor collapse in Gandhidham. Clear separation of concrete & steel in the reinforced concrete wreckage (left) and demolition with hand-held hammer by the man standing at the top (right) provide some indication of the quality of materials used.

Figure 44. Collapsed ground floor (inset: close-up view) of Children's Hospital and Research Center in Gandhidham, indicating a typical nature of soft ground floor failure.

Sharma Resort Near Gandhidham

Figure 45. The collapsed wing of the luxury resort that was still in business, where authors spent overnight. The top inset is a photograph taken from the photograph the owner was kind enough to show to the authors and shows how the building looked before collapse. The inset to the right is the entrance to the reception area.

Figure 46. Closer view of the collapsed wing at Sharma Resort. Tents in the foreground were arranged by the owner for renting to the prospective customers. Some of rooms in the blocks that had not collapsed were also available for renting. The authors opted for the tent.

Figure 47. View of the collapsed block at Sharma Resort during construction. Again a photograph from the picture the owner kindly showed the authors. It is clear that the building consisted of reinforced concrete frame structure with infill brick masonry wall. This system of construction is typical of the reinforced concrete buildings in the region.

Chaubari Area

Figure 48. Damage scenes from the Chaubari area, to the east and close to the probable epicentral area. The top two photographs are of the compound of the damaged old age home. Lower left shows the severe nature of damage to reinforced concrete building in Chaubari. The lower right photograph shows the surviving simple concrete structure of a resting place in the midst of a completely destroyed village in Chaubari area, seemingly consisting of non-engineered houses. The tents accommodate survivors can be seen in the background.

GENERAL OBSERVATIONS AND REMARKS

As mentioned in the beginning, this report by the authors is based on the preliminary observation of the building structures affected by the earthquake in Gujarat, western part of India on January 26, 2001. Considering the preliminary nature of the actual field observation, as well as the compilation of this report, no attempt is made to discuss and describe in detail the different cases of structural failure of building structures given in the preceding section. The captions in the respective figures are mostly the general impressions of the authors based on simple observations during field visit and are not based on factual confirmation. Some of the general points noted are as follows:

1. The earthquake occurred in the area that was recognized as the seismically active region adequately designated as having the highest seismic risk in zoning map of India However, public awareness of the fact seems to have been poor at the best.
2. The shaking due to the main event of the earthquake wrecked severe devastation in Gujarat, particularly in the Kachchh region, and bordering areas of Pakistan. Shocks of the earthquake were felt over a very wide area, as far away as Culcutta and also in Bangladesh and Nepal.
3. Damage to reinforced concrete and masonry building structures, as well as to the different types of non-engineered houses, in the areas covered by the authors during the field visit, were noted to be primarily due to ground shaking, and not due to ground failures due to various reasons.
4. Most of the several storied buildings have a structural system consisting of reinforced concrete frames with infill brick masonry, mostly supported on direct foundations. In addition, many of these buildings have the first floor left open and without infill walls, the space being used as parking lots or for shops, resulting in ground floors to be softer relative to upper floors.
5. A significant portion of the failure of several storied reinforced concrete buildings resulted from the collapse of soft ground floor. In most cases, the upper floors of these buildings remained intact because of the effect of added lateral stiffness due to presence of masonry infills, when compared to the open ground floor. The benefit of energy absorption mechanism from faiilure of ground floor, may have inadvertently served as a seismic isolator to keep upper floors intact.
6. Noncompliance to seismic provisions in the building design as well as the lack of quality control in construction seem to be dominant in causing the staggering extent of failure to engineered building structures, resulting in the numerous casualties.
7. During field observation of damage to building structures, the authors noted frequent instances of significantly larger movement of damaged or failed structures in the north south direction. It is not possible to be conclusive, but it is possible that it may be due to stronger earthquake motion in the north south direction.
8. A significant portion of houses damaged and resulting in casualties seem to have been non-engineered structures. Considering the common practice of non-engineered construction in the region, reconstruction and rehabilitation initiatives would face unparalleled challenge if the same mistakes are not to repeat in future earthquakes.
9. The source mechanism of the earthquake is not yet clear to the authors beyond the summary provided by USGS based on the teleseismic data from the main shock. In addition, considering the preliminary nature of observations, a coherent assessment has not been possible. The authors look forward to results of more detailed observation trips by colleagues subsequently.

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