GUJARAT (KUTCH) INDIA
EARTHQUAKE OF JANUARY 26, 2001
Lifeline Performance

Edited by John M. Eidinger

Technical Council on Lifeline Earthquake Engineering
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Abstract

The January 26 2001 Gujarat Earthquake (M_w = 7.7) severely struck the Kutch District of the Gujarat State, India. The earthquake occurred on a blind thrust fault in western India, about 150 km northwest of the city of Ahmedabad. The earthquake resulted in about 17,000 fatalities, 150,000 injuries and left more than 500,000 homeless in the stricken areas. The heaviest damaged lifelines were water and electric power. Other lifelines were substantially impacted, including communications, wastewater, ports, railways, highways, roads and bridges. The speed of recovery of the water and electric power systems was substantially slowed due to widespread heavy damage to pump station and substation control buildings.

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Foreword

The Earthquake Investigations Committee of the Technical Council of Lifeline Earthquake engineering (TCLEE), American Society of Engineers (ASCE), is established to initiate, organize, train for, coordinate and evaluate the performance of lifelines following earthquakes. Members of the committee are employees of lifeline industries, consulting engineers, and academics from the United States, Canada and Hong Kong. Committee members provide services on a voluntary basis. For most non-USA earthquake investigations, companies of some members provide in-kind support to offset the funding from ASCE. In addition to the reconnaissance trip expenses, many man-weeks of effort by individual contributors were required to complete this report.

Individuals participating in the investigation need not be members of the Committee or members of ASCE, but are expected to follow the Committee's earthquake investigation practices as described in the ASCE publication, "Guide to Post-Earthquake Investigation of Lifelines". Members of the investigation team coordinate with other groups and may participate in groups organized by other organizations. They gather performance data, both good and bad, from earthquakes in order to provide information for practitioners to improve the performance of lifeline systems. The earthquakes that have been investigated by this committee include: (outside USA) the 1985 Chile, 1988 Soviet Armenia, 1990 Philippines, 1991 Costa Rica, 1992 Turkey, 1995 Kobe, 1999 Turkey (Izmit), 1999 Chi Chi (Taiwan), 2001 El Salvador earthquakes; (within USA) 1989 Loma Prieta, 1992 Landers, 1994 Northridge, 2000 Napa, 2001 Nisqually earthquakes.

The Earthquake Investigations Committee works closely with the Earthquake Engineering Research Institute to provide an abbreviated version of lifeline performance in Earthquake Spectra, an EERI publication.

John Eidinger, Editor
April 1, 2001

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1.0 Introduction

1.1 Highlights of the Earthquake

General. On January 26, 2001 at 8:46 local time, there was a magnitude 7.7 (M_w) earthquake in the seismically active area of the Kutch (alternate spelling Kachchh) District of the Gujarat State of India about 600 km northwest of Mumbai (Bombay). The town of Bhuj is centrally located in the Kutch District, and this earthquake is alternatively known as the Bhuj earthquake. Figure 1.1 shows a map of the Kutch District in Gujarat State. It is estimated there were nearly 20,000 deaths, 150,000 injuries and 15,700,000 people affected by the earthquake in the State of Gujarat (1991 population – 37,800,000). In the Kutch District, about 258,000 houses (90% of the housing stock) was damaged or destroyed. In the entire Gujarat State, about 839,000 houses (about 24% of the housing stock) was damaged or destroyed. Most of these buildings were non-engineered, unreinforced stone masonry buildings. However, there were many instances of collapse of engineered reinforced concrete structures.

Figure 1.1. Map of Kutch District

Geotechnical. There was extensive surface cracking in the area near Bhachau, which caused damage to main highway bridges, water pipelines and two railroad track bridges.

Liquefaction caused severe damage to facilities in the Kandla Port south of Gandhidham and major damage to the Navlakhi port southeast of Gandidham on the southern shore of the Gulf of Kutch in the Rajkot District. At Navlakhi, there was extensive lateral spreading and subsidence, which caused the main access road and railroad track to drop below sea level at high tide interrupting the transport of coal and other goods from the port. In addition, lateral spreading caused a new reinforced concrete wharf to collapse into the sea. There was no significant surface faulting for this earthquake with a hypocenter depth of 10 km. There was extensive evidence of liquefaction in various areas of the Kutch district including numerous sand boils in dry lakebeds northeast of Bhuj. After the quake, these sand boils had fountains of saline ground water rising 2 to 3 meters.

Water. There was extensive damage to the water pumping and pipeline transmission system. The bulk of the observed pipeline damage was due to liquefaction or soil compaction at stream crossings. Many pump buildings constructed out of unreinforced stone collapsed in the strong shaking areas; the collapsed structures damaged electrical controls and emergency generators, but not the pumps and motors. Most seismically-designed elevated reinforced concrete tanks performed well; although there were two reported collapsed tanks out of more than 100 in the strong shaking area, three or four had minor to major leaks, and many more had observable structural damage but remained leak tight. Restoration of potable water supply via pipeline to all towns and villages which had such service before the earthquake is projected to take about 4 to 6 months. In the meantime, potable water is being distributed via tanker truck, with about half the affected population in the Kutch District so served as of one month after the earthquake.

Highways. The road, highway and bridge system performed very well, even in the area with severe ground shaking. There was one collapsed reinforced concrete slab culvert due to failure of its unreinforced stone abutment. Bridges performed very well and with one exception, were useable after the earthquake. This highway network played a critical role in the transportation of emergency supplies into the damaged regions.

Electric Power. There was extensive damage to medium to high voltage (66 kV, 132 kV and 220 kV) substations in the high shaking areas causing immediate power outages. Most of the substation control buildings were either severely damaged or collapsed destroying or heavily damaging control equipment. Temporary controls were in place and power was restored to all 220-kV, 132-kV and 66-kV systems by February 9, 2001. There was no reported significant damage to high voltage electrical transmission lines. There was no reported damage to power generation plants. All the fossil and nuclear power plants are located over 150 km from the epicenter. Falling power poles and buildings heavily damaged local distribution power systems; however, restoration was not a high priority due to limited demand in those areas. Pole and platform mounted transformers were adequately braced and were not reported to have failed.

Telecommunications. Telecommunications facilities suffered damage at central office buildings that were constructed of reinforced concrete with stone in-fill walls. In Bhuj, 50% of the walls collapsed at the main Central Office, but the reinforced concrete structure remained standing with only minor damage. The wall collapses damaged interior electrical controls and caused human casualties. Fiber optic cables were severed causing significant interruptions in service. Within one week of the earthquake, phone service was available to anyone that requested it. Cellular service, which was limited before the earthquake, was mostly restored when electrical power was restored.

Hospitals and Emergency Relief. Hospitals in Bhuj and Anjar were totally destroyed. The Indian military provided immediate emergency support, which was soon followed by international relief efforts. The International Federation of the Red Cross and Red Crescent Societies provided a mobile hospital, medical doctors, relief workers and relief supplies to the stricken areas of Kutch. The Red Cross temporary hospital will remain in Bhuj until a replacement hospital is constructed. The Red Cross distributed food, water and tents to the stricken areas. In addition, they worked with local officials to restore a potable water supply and maintain sanitary conditions.

Debris. The Gujarat Bureau of Roads and Buildings Department (R&BD) is responsible for both the restoration of the roads and the removal of building debris. There was limited heavy equipment available for the removal of the rubble. R&BD enlisted private truckers and animal drawn carts to remove the debris from the cities, towns and villages. Rubble was either stockpiled along roads or in floodplains. The lengthy time needed for debris removal is a factor in the slow process of other critical infrastructure restoration efforts.

1.2 Lessons Learned

This report highlights the damage and impacts to the various lifelines in Gujarat State. With regards to "lessons learned" we highlight the main impacts on lifelines in this earthquake that have not usually been seen in other earthquakes.

First, there was relatively little ground failure that directly affected buried utility infrastructure. The four year long drought in the area may have contributed to abnormally low water tables. There was no surface faulting, even in this high magnitude shallow earthquake. There were essentially no landslide failures that affected the built environment. This led to less damage to buried pipelines than would otherwise have occurred.

Second, there was a huge rate of damage to the bulk of the housing stock. This led to a great dislocation of people away from their normal dwellings. This has led to a much higher effort to bring emergency lifeline services (water, wastewater, power, etc.) than would otherwise have been necessary. Allocation of a high percentage of emergency relief efforts to bringing lifeline services to dislocated people has slowed efforts to restore normal service to the communities.

Third, there was a very high rate of damage to utility owned critical buildings. These critical buildings include electric substation control buildings, telecommunication central offices, water well and pump station buildings, and airport control towers. The reason for this damage is that the buildings were not designed or built to any rational seismic standards. Substantially suitable seismic standards had been in place for the Kutch District of India for at least 15 years prior to the earthquake, but the utilities seemed to have widely (but not always) ignored them. The damage to the utility buildings led to substantially longer utility service disruptions that would have otherwise have occurred.

Longer than needed disruptions to telecommunications and power led to particularly difficult coordination of emergency relief efforts.

Fourth, there was a reasonably low rate of failure of utility-owned structures that had been designed to suitable seismic standards. While the existing seismic standards in India are perhaps not as rigorous at they could be, they did afford a substantial level of seismic protection when they were applied. It is reasonable to state that if the existing standards had been applied uniformly for all structures, including those used for dwellings, then perhaps 90% of all casualties would have been avoided.

Fifth, there was a high rate of minor to moderate damage to the region's highway bridges, especially those that had not been designed for earthquake forces. It was very fortunate that there were adequate detours available at locations with heavily damaged bridges, as the drought left most river and stream beds dry and passable by vehicles. If this earthquake had occurred during the monsoon season, the failure of the bridges would have led to much more severe disruptions in ground transportation and emergency relief efforts.

Sixth, there were no reported fires following this large earthquake. This may be because there are no natural gas pipeline distribution systems in the area, wood is not used as a building material, and there were long outage times to the electric power system. In combination, these factors precluded sources of ignition and fuel supply for fires.

Seventh, there was little evidence of good seismic detailing practices for utility-owned equipment. This suggests that there remains a lack of knowledge and/or a lack of financial commitment to make proper use of available seismic design guidelines for utility infrastructure. More effort is needed by organizations such as the ASCE and its counterparts around the world to disseminate seismic design guidelines for utility infrastructure. In the United States, it is common for utilities to "self-regulate" and adopt on their own an acceptable level of seismic design. In countries such as India, such "self-regulation" might not achieve the desired safety levels as the knowledge and resources are not widely available. Perhaps it might be efficient to require utilities in developing nations to adopt minimum seismic design guidelines for all components needed to provide at least minimum levels of post-earthquake service.

1.3 Investigation Team

The Post Earthquake Investigation Committee of the Technical Council on Lifeline Earthquake Engineering (TCLEE), a technical council of the American Society of Civil Engineers (ASCE) organized a team of three TCLEE members with support from ASCE and PEER to perform a reconnaissance of the lifeline in the earthquake area. This group is referred to herein as the investigation team. The investigation team started the reconnaissance effort on February 21, 2001 and completed the efforts on March 4, 2001. The investigation team consisted of the following ASCE members:

Mr. Curtis Edwards, Pountney & Associates, Inc. 4455 Murphy Canyon Rd #200, San Diego, CA 92123 (cedwards@pountney.com) (team leader).

Mr. John Eidinger, G&E Engineering Systems, Inc., 6315 Swainland Rd, Oakland, CA 94611 (eidinger@earthlink.net) (editor)

Mr. Mark Yashinsky, Caltrans, Sacramento, CA (mark_yashinsky@dot.ca.gov).

The various chapters in this report have been prepared as follows:

Primary chapter authors:

Chapters 9 (Communications), 11 (Ports), 13 (Emergency Response). Curt Edwards

Chapter 8 (Highways). Mark Yashinsky

Chapters 1 (Introduction), 2 (Seismology and Geotechnical), 3 (General Building Stock), 4 (Water), 5 (Wastewater), 6 (Dams), 7 (Electric Power), 10 (Oil and Liquid Fuels). John Eidinger (editor)

This report reflects inputs from many other people, including Mr. Bill Lettis (Seismology and Geotechnical, chapter 2), Mr. Alex Tang (Telecommunications, chapter 9), Mr. Anshel Schiff (Electric Power, chapter 7), Mr. Don Ballantyne (Water, Wastewater, Electric Power, chapters 4, 5, 7).

Due to the nature of post-earthquake investigations, it is quite possible that even though every attempt was made to verify the accuracy of the information in this report, this report could still contain inaccuracies and/or incomplete data. The authors apologize in advance to all those people who will point out new, updated or corrected findings and observations.

1.4 Abbreviations

MMI	Modified Mercalli Intensity
GEB	Gujarat Electric Board
GoG	Government of Gujarat
GoI	Government of India
GWB	Gujarat Water Board
GWSSB	Gujarat Water Supply and Sewage Board (now the GWB)
Mw	Moment Magnitude
M	Magnitude
M_L	Local Magnitude
NGO	Non Government Organization
PGA	Peak Ground Acceleration (g)
R&BD	Roads and Bridges Department of Gujarat State
WTP	Water Treatment Plant

1.5 Place Names

Several place names use various English spellings, depending upon source and map. To simplify interpretation, we note below the various spellings used for the same place in this report and commonly available maps of the area. In most places in this report, we use the first noted spelling indicated as follows.

Kutch, Kutchh , Kachchh

Gandiham, Gandhiham

Gandinagar, Gandhinagar

Ahmedabad, Ahmnevad, Ahmnabad

1.6 Acknowledgments

The investigation team would like to acknowledge the assistance of a number of groups and individuals that contributed to the success of this investigation.

1. Mr. Walter Hays and Mr. Jon Esslinger, ASCE for providing technical support and financial assistance for the investigation.
2. Ms. Yumei Wang, Senator Edward Kennedy's office for coordination with the American Red Cross and soliciting support.
3. The American Red Cross for providing valuable field support, without which, our investigation would not have been successful. We would like to specifically thank: Mr. Langdon Greenhalgh for making the initial transportation arrangements; Mr. Nick Denton for providing local resources and information related to our efforts; Mr. Steve McAndrew for providing detailed damage information to aid us in focusing our investigations; Dr. Gordon Dodge for tolerating the new roommates; and, Ms. Carolina Jules who took care of the rental car arrangements and generally made our lives easier during our stay.
4. Mr. H.J. Kazia, Superintendent Engineer, Gujarat Water and Sewer Board. Mr. S. C. Patel, Gujarat Water and Sewer Board in Bhuj.
5. Mr. S. V. Machhur, Superintendent Engineer, Gujarat Electricity Board, Bhuj.
6. P.N. Pandya, Executive Engineer, R&B Division, Bhuj
7. Mr. S. T. Bus, Superintending Engineer, G.E.B. Anjar
8. Mr. K.D. Jadeja, Chief Engineer, Gujarat Water and Sewer Board.
9. Mr. Chitkara, Director, Ahmedabad Airport
10. The Times of India
11. Earthquake Engineering Research Institute (EERI)
12. MSNBC-India

13. Mr. Patrick Doust, of the Turkish Red Cross, via Notre Dame de Grace, Montreal.
14. Statistics and damages were obtained from interviews with the local Bhuj telecommunications staff.

Local officials should be commended for the time they took from their busy restoration/relief efforts to provide us with the data and information contained in this report.

1.7 Copyright

2.0 Seismology and Geotechnical Considerations

2.1 Seismic Setting

Gujarat is a highly earthquake-prone region. Devastating earthquakes have rattled nearly all parts of the state. Figure 2.1 shows the locations of some recent earthquakes that have affected India. Table 2-1 lists 12 significant earthquakes that have shook Gujarat State since 1819.

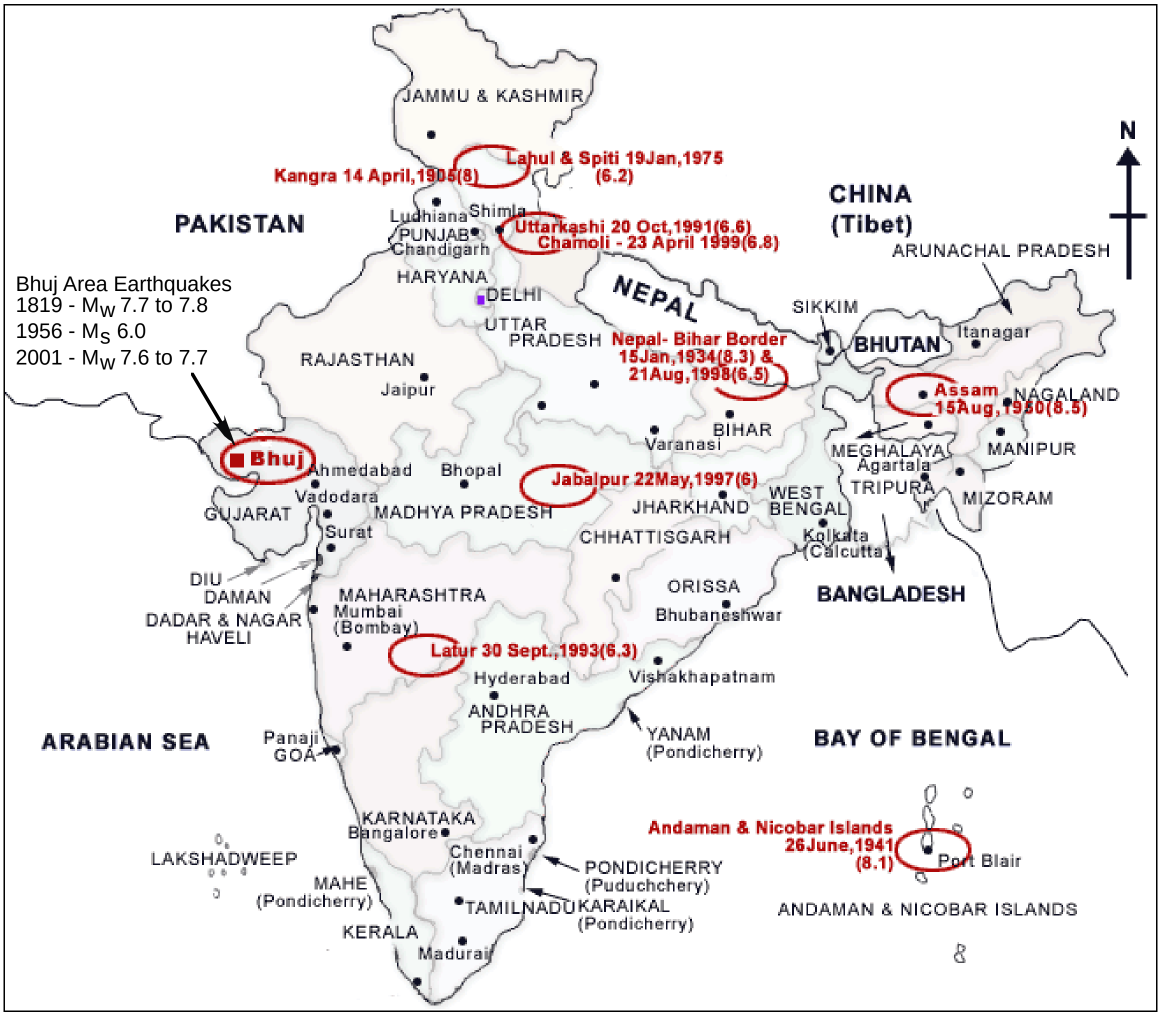

Figure 2.1. Major Earthquakes in India and Bhuj Area

Date	Where	Magnitude	MMI	Latitude	Longitude
6-16-1819	Great Rann [1]	7.8	XI		
8-13-1821	Kaira-Daman-Ahmedabad	5.0	V	22.0	72.0
6-19-1845	Southeast of Lakhpat	6.3	VII	23.8	68.9
4-26-1848	South of Mount Abu	6.0		24.4	72.7
4-29-1864	Surat-Ahedabad area	5.0	VII	22.3	72.8
1-14-1903	Northeast of Kunria	6.0		24.0	70.0
4-21-1919	Near Bhavnagar	5.5	VII	22.0	72.0
10-31-1940	Northwest of Kathiawar, Jamnagar District	6.0	VI	22.5	70.4
7-21-1956	North of Anjar [2]	M_w 6.3		23.0	70.0
3-23-1970	Bharuch District [3]	M_L 5.4		21.7	73.0
9-12-2000	NE of Bhavnagar [4]	M_L 4.4		21.8	72.2
1-26-2001	Near Bhachau	M_w 7.6-7.7	IX-XII		

Table 2-1. Historical Earthquakes in the Gujarat Area

Notes to Table 2-1.

[1] The Great Rann of Kutchh Earthquake. This is one of the biggest earthquakes in Western India. It had a magnitude of about 7.8 (A. Johnston) and was felt over a wide swathe of the Indian sub-continent. 3,200 people were killed (some reports suggest as few as 1,550 killed) and hundreds of towns were either destroyed or badly damaged.

This quake was also associated with surface faulting and subsequent subsidence in the epicentral area. This fault produced a scarp called "The Allah bund" and its creation was witnessed by the entire population in the region.

[2] This was the deadliest post-Indian-independence earthquake in Gujarat. At least 156 people were killed and hundreds of buildings were either damaged or destroyed in Anjar, Bhuj, Gandhidham, Kandla and other towns along the northern shore of the Gulf of Kutchh.

[3] 30 people were killed in this earthquake in Bharuch and the neighboring villages. The quake was also felt in Ankleshwar, Surat, Baroda and Bhavnagar.

[4] 1 person was injured and scores of buildings were damaged in this tremor. It was the largest shock in a seismic swarm that began in 1999 and began to peak in August 2000.

In Kutch, the Indus River delta complex zone located at the international border with Pakistan in its present form provides an interesting configuration and topography. It shows profound influence of various faults -- Nagar Parkar Fault/Luni-Sukri Fault, Island Belt Fault/Allah Band Fault, Banni Fault and Kach Mainland Fault.

Its northern flank is delimited by an E-W fault. This tectonic lineament shows signatures of reactivation during Pleistocene and is also well evidenced by frequent seismicity. A large part of the delta forms a more or less semi-circular terrain bounded to the south by a curvilinear system of faults which separate it from the deeper parts of the Rann, which come under tidal inundation. This truncation is obviously due to a number of fault related geomorphic changes, which affected the then existing delta complex, uplifted and tilted parts of it northward and pushed below a substantial part of it beneath the shallow sea. This region has suffered the most number of earthquakes in Gujarat and also the largest earthquake in the state in 1819. In 1668, a quake with an estimated magnitude of 7.8 struck just across the border, in Pakistan's Sind Province, its epicenter lying approximately between Karachi and Hyderabad (Sind). The eastern parts of Gujarat sit on the Cambay Rift. This feature runs from Mehsana, towards the gulf of Khambat. The western flanks of this fault zone enter the Gulf while the eastern flanks terminate just east of Bharuch. The Narmada Valley rift zone is the dominant feature in the Surat region. The area south of Surat also marks the beginning of the West Coast Fault, which runs along the Konkan towards Ratnagiri. The north-eastern part of Gujarat are affected by the Rajputana fault zone, which extends from Mehsana along the Aravallis into Rajasthan. Bhavnagar and Dharmapur Districts have experienced earthquake swarms.

2.2 Hazard Zonation

Gujarat primarily lies in three different seismic zone regions, as defined by Indian Standard 1893. The Rann of Kutch (Kutch District) and regions along the Pakistan border come under Zone V (highest hazard seismic zone). A narrow fringe of the northern Kathiawar Peninsula i.e. Jammagar District and the remaining parts of the Rann of Kutch come under Zone IV. The remaining districts of Rajkot, Surendernagar, Mehsana, Banaskantha, Sabarkantha, Panchmahal, Baroda, Kheda, Ahmedabad, Bhavnagar, Amreli, Junagadh, Bharuch, Surat, Valsad, Dang (Ahwa), and Gandhinagar along with the Union Territory of Diu lie in Zone III. (Figure 2.2).

Implicit within the Indian Standard 1893 for earthquake design forces in that the Zone V regions of India, including the Kutch region, could expect to experience a maximum peak ground acceleration (PGA) in the range of 0.24g, within the reasonable planning horizon for many engineered structures. Explicit seismic design forces in Indian Standard 1893 will be described in detail in this report. For Indian Zone V, seismic design forces are about 60% that commonly specified by the UBC (1994 version) for Zone 4 regions of California. Indian Zones IV and III seismic design forces 65% and 50% of that for Zone V, respectively.

Following this earthquake, it is understood that efforts are underway to update the seismic zone map shown in Figure 2.2. Changes to Indian Standard 1893 may also be warranted.

2.3 Fault Mechanism

The Gujarat earthquake of January 26, 2001 occurred at 8:46 am local India time. The largest town in the very strong ground shaking area was Bhuj, which is located in the central Kutch District. Figure 2.3 shows a preliminary map of the epicentral area in Kutch and a rectangle depicting the fault plane. The beach ball like figure is a stereographic projection of the fault planes - a blind thrust reverse fault.

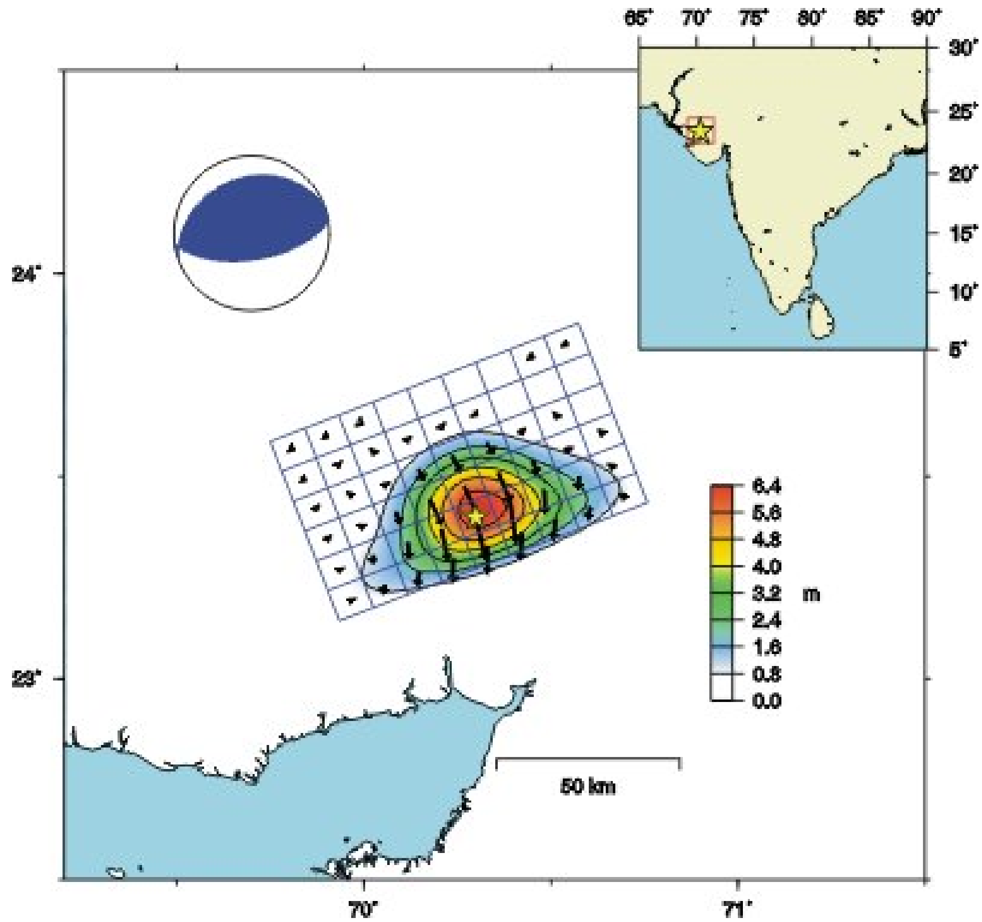

Figure 2.3. Fault Plane (From U. Tokyo)

One preliminary interpretation of the fault mechanism is shown in Figure 2.3. In this interpretation, the fault plane is orientation is N69°E with a dip of 29° towards the Northwest. The hanging wall is located on the northern face. Figure 2.3 shows that the maximum movement at the hypocenter located about 10 km depth is of the order of 6 m and on the surface the movement is more than 1 m over a distance of about 32 km.

Alternate interpretations of the fault are still ongoing as of early April, 2001 (Lettis, Sommerville, et al). The fault may in fact have a dip of about 60° towards the southeast and a hypocentral depth of about 17 km; the surface projection of the fault plane would be similar to that shown in Figure 2.3. This alternate interpretation would appear to be in keeping with the observed patterns of damage in the Kutch District.