Isoseismals for the Kutch earthquake of 26th January 2001

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Damage observed during the Kutch earthquake of 26th January 2001 is classified according to the type of structure. This damage pattern has been used to draw the isoseismal map on the basis of the intensity scale given in IS 1893–2002 which covers only traditional one to two storey houses. Having thus estimated intensities, and observed damage to other types of structures, a new criterion was adopted which is included in this paper. Areas that showed maximum damage to structures have been assigned maximum intensity X.

1. Introduction

The isoseismal map (figure 1) for the Kutch earthquake of January 26th, 2001 (m 6.9) was drawn on the basis of a composite damage survey of several kinds of buildings. These included houses in rural and urban areas and reinforced concrete buildings of schools, hospitals, community inns and government offices. The survey also included temples; 4–6 storey buildings; infrastructure buildings such as overhead water tanks, substations of Gujarat Electricity Board, roads, bridges, industrial buildings and oil installations; and ground damage (Bose *et al* 2001; Prakash *et al* 2001 (a,b,c,d,e,f); Saraf *et al* 2001, 2002; Sinvhal *et al* 2001 (a,b,c,d,e,f,g) 2002). For each type of structure it was important to judge the quality of construction and the presence of critical deficiencies. No landscape changes, barring soil-liquefaction, were observed anywhere, and therefore the maximum intensity assigned is limited to X.

On the basis of the criteria given in table 1, intensity values were assigned to different sites (table 2) along with notable structural and ground damage. Table 3 gives the geographical coordinates of the places listed in table 2, most of which are plotted in figure 3. Damage pattern, seismotectonics and isoseismals for the Kutch earthquake of 26th January 2001, suggest that the area of maximum intensity X was controlled by the complex tectonics of the area. Heavy damage and destruction to multistorey buildings in Ahmedabad (epicentral distance > 250 km) and in Surat (epicentral distance > 350 km) are attributed to a number of critical deficiencies in design and construction, aggravated by the ground response of soft alluvium of the Cambay basin and rivers. Multistorey buildings in areas of thick alluvium have shown more damage compared to similar buildings in hard rock areas.

Failure of columns occurred at ground storey level in most multistoreyed buildings in Bhachau, Anjar, Gandhidham, Bhuj, Ahmedabad and Surat. In the ground storey of these buildings the walls were not provided for creating parking space. The storeys above had both columns and walls. This caused the ground storey to become weak in comparison to the storeys above and resulted in concentration of damage in the ground storey columns.

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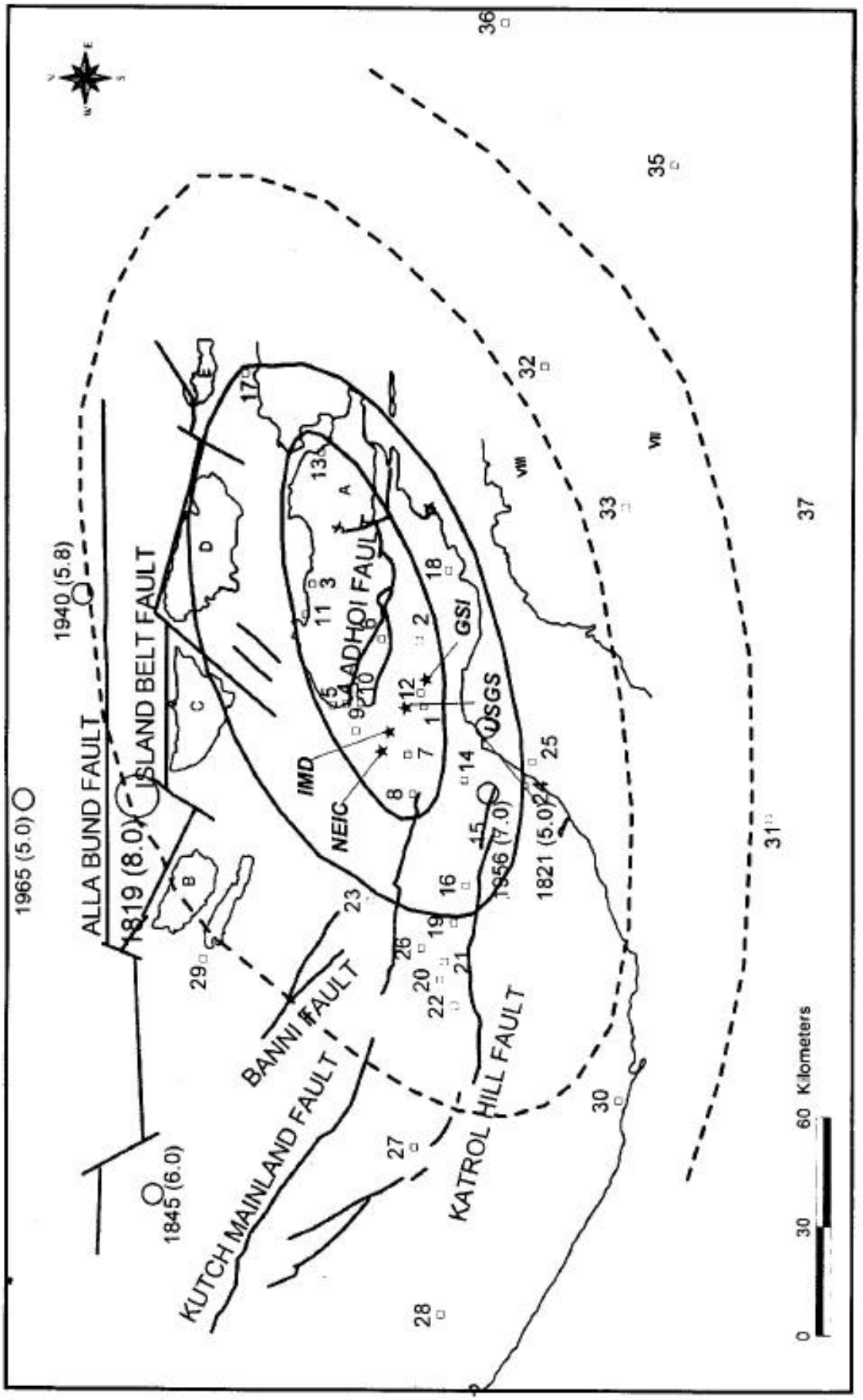


Figure 1. Isoseismal map for the Kutch earthquake of January 26th, 2001, superposed on the tectonic map of Kutch (after Biswas and Deshpande 1983). **A:** Wagad Ridge, **B:** Paccham Uplift, **C:** Khadir Uplift, **D:** Bela Uplift, **E:** Charor Uplift. Stars show epicenters of this earthquake provided by different organizations. Locations of important places of the affected area are numbered and refered to in tables 2 and 3. Circles show epicentres of previous earthquakes in the region.

Table 1. *Criteria adopted for assigning intensity values, extended after IS:1893–2002.*

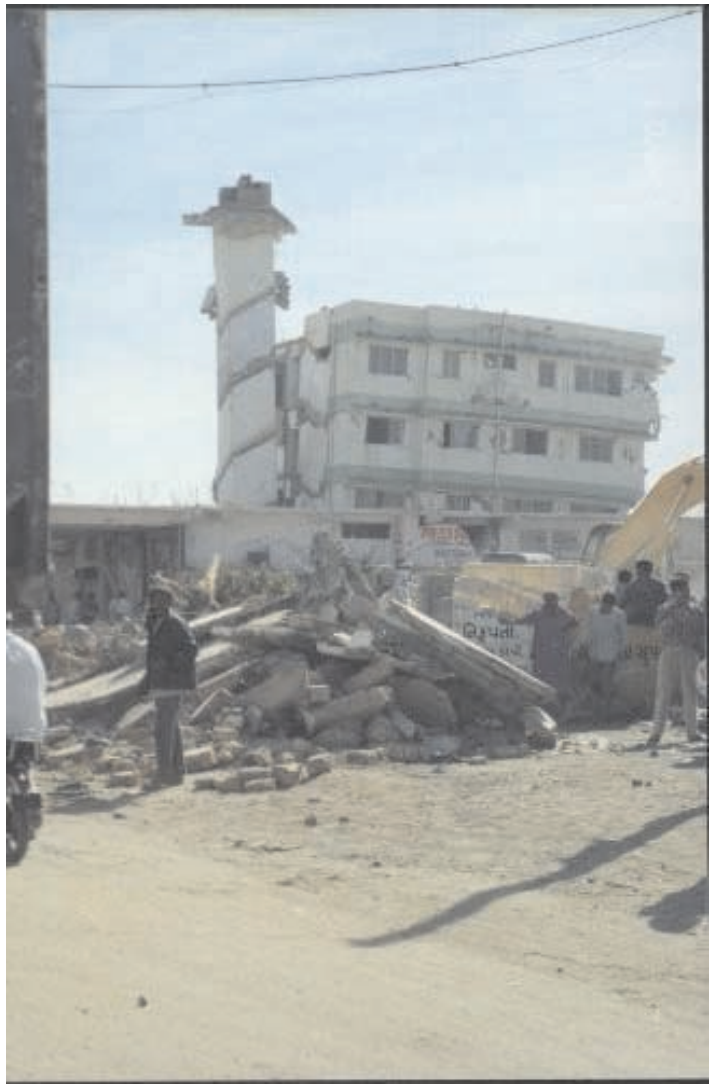
Building type	Grade of damage at different MMI intensities				
	VI	VII	VIII	IX	X
Traditional rural houses in random rubble stone masonry	Moderate	Heavy	Destruction	Collapse	Collapse
Load-bearing masonry wall buildings with reinforced concrete beams and slabs of					
• three storey	Slight	Moderate	Heavy	Destruction	Collapse
• two storey	Slight	Moderate	Moderate	Heavy	Destruction
• single storey	-	Slight	Slight	Moderate	Heavy
Temples			Heavy	Collapse	Collapse
Municipal overhead tanks			Slight	Slight	Moderate
Roads and road bridges			Slight	Slight	Moderate
Industrial buildings on firm ground			Slight	Moderate	Heavy
4 to 10 storeyed reinforced concrete buildings having suitable architectural configuration for earthquake resistance	Slight	Moderate	Heavy	Destruction	Collapse
4 to 10 storeyed reinforced concrete buildings not having suitable architectural configuration for earthquake resistance (figures 2 & 3)	Heavy	Destruction	Collapse	Collapse	Collapse

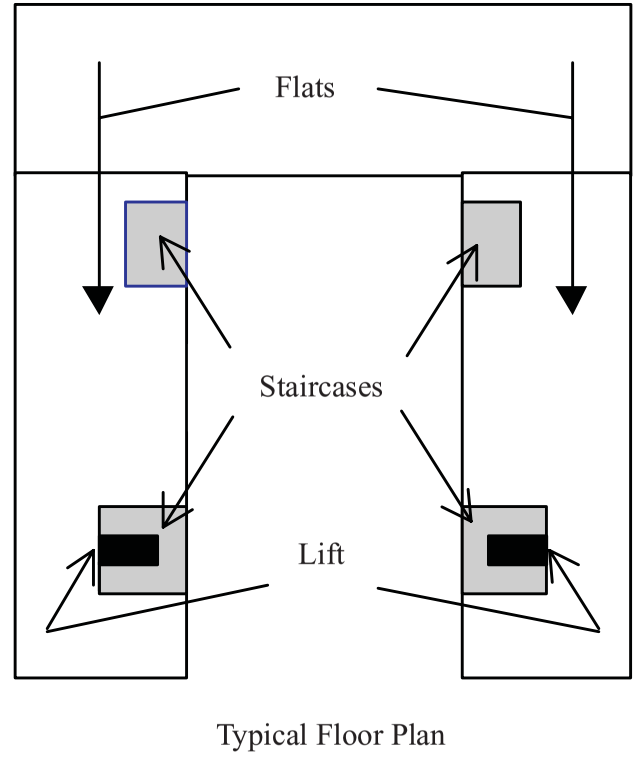
Table 2. *Intensity (MMI) of places according to observed structural damage. The table is arranged in descending order of intensities, as the damage survey was more exhaustive in areas of higher intensities. Superscripts refer to numbers given in figure 1 (after Sinvhal et al 2001) and table 3.*

Intensity	Classification of structural damage as per IS:1893–1984			Places visited	Notable structural damage	Notable ground damage
	Type of structure	Grade of damage	Quantity			
X	C	4	Many	Bhachau[1], Samakhiali[2], Rapar[3], Manfara[4], Kadol[9], Chobari[5], Adhoi[6], Amardi[7], Dudhai[8], Kharoi[10], Trambau[11], Vondh[12], Adesar[13], Bhimasar[14] (Rapar)	In Manfara, Trambau, Bhachau, Rapar and Samakhiali, even well-built RC structures were totally devastated. In all RC buildings, even those under construction, all columns and joints buckled and failed. A large number of 66 KVA GSEB substations collapsed.	Extensive liquefaction resulted in mud-flows in Chang Nadi for several kilo-meters between Manfara-Chobari villages. Water fountains were reported in Bhachau, Samakhiali, Amardi, Dudhai villages. Fissures in roads within and in roads leading to this region were numerous.
		5	Few			
	B	5	Many			
	A	5	Most			
IX	C	3	Many	Anjar[15], Ratnal[16], Santalpur[17], Surajbadi Bridge[18]	Anjar, a 450-year-old town, was destroyed in the Anjar earthquake of 1956. New houses were later raised on old foundations. Addi-tional storeys were added on top of these. Such constructions in the congested old Anjar were destroyed. Isolated 4 storeyed modern build-ings could be seen with moderate damage.	The soil below Surajbadi bridge is marshy. Fissures and water fountains were observed here. Many new pools of water were observed between Bhachau and Bhuj, north of the road and elongated along it. These were about 3 meters long and 2 meters wide. These and other water bodies were also seen in satellite images.
		4	Few			
	B	4	Many			
		5	Few			
	A	5	Many			

Table 2. *(Continued)*

VIII	C	4	Many	Kukma[19], Bhuj[20], Madhapar[21], Sukhpur[22], Kotada, Lodai[23], Ghadsisa, Gandhidham[24], Kandla[25], Radhanpur[26].	In Bhuj, dense clusters of two and three storey houses and shops existed on both sides of narrow streets, like in Vaniawadi locality. These collapsed on to the street and blocked all rescue and relief efforts. The new RC framed construction, with obvious weaknesses, fared poorly. In Gandhidham tall buildings with infirmities showed a dismal performance.	Fissures in roads were as wide as 15–20 centimeters at several places, e.g., near Ghadsisa. Liquefaction and water fountains occurred in Kaswali Nadi near Lodai.
		3	Few			
	B	3	Most			
	A	4	Most			
VII	C	1	Many	Nakhtarana[27], Naliya[28], Undot, Khawda[29], Mandvi[30], Jamnagar[31], Halvad[32], Morvi[33], and some pockets of Ahmedabad[34]	Poorly constructed GSEB houses in Nakhatrana were destroyed. Water fountains were witnessed at Undot at the time of the earthquake, near Mandvi. Between Moti Undot and Gadsisa several culverts were broken and temples destroyed.	
	B	2	Many			
	A	3	Most			
		4	Few			
VI	B	1	Many	Surendranagar[35], Viramgam[36], Rajkot[37], Gandhinagar[38], Ahmedabad[34], Surat[39], Vadodara[40], Broach[41] and the rest of Gujarat.		
	A	1	Many			
		2	Few			





Figures 2 and 3. Sahil Apartments at Gandhidham and floor plan. People connected with the salt trade lived in these 300 modest apartments of 2 bedrooms, a hall, a kitchen and toilets. In this 5 storeyed building the ground floor was a soft storey and was used for parking. The middle arm of this C shaped building had shops at ground level, which extended to the upper floor in the form of a plaza.

Balconies, like in many other places, were connected to rooms. Due to the change in floor area of flats, placement of filler walls changed from third floor upwards which introduced a change in vertical stiffness.

This building had two lifts and four staircases. The staircase was raised spirally along the sides of lift well. Connection between the slab and shear core was missing. The diaphragm was not well connected to the lift core to transfer the shear. Huge water tanks were placed on top or near the staircase/lift core, in all wings.

Table 3. *Geographical coordinates of places marked in figure 1 and listed in table 2.*

Map ID no.	Place	Longitude ° ' "	Latitude ° ' "	MMI
1	Bhachau	70 20 33	23 18 46	X
2	Samakhiali	70 30 20	23 19 20	X
3	Rapar	70 38 35	23 35 05	X
4	Manfara	70 20 58	23 30 07	X
5	Chobari	70 20 42	23 32 04	X
6	Adhoi	70 30 37	23 24 51	X
7	Amardi	70 13 21	23 21 05	X
8	Dudhai	70 07 31	23 20 18	X
9	Kadol	70 16 52	23 28 40	X
10	Kharoi	70 21 05	23 28 02	X
11	Trambau	70 34 11	23 36 01	X
12	Vondh	70 22 35	23 19 10	X
13	Adesar	70 58 15	23 33 49	X
14	Bhimasar (Rapar)	70 09 37	23 12 44	X
15	Anjar	70 01 43	23 08 07	IX
16	Ratnal	69 53 58	23 12 32	IX
17	Santalpur	71 10 00	23 45 00	IX
18	Surajbari bridge	70 40 40	23 15 05	IX
19	Kukma	69 48 27	23 14 14	VIII
20	Bhuj	69 39 59	23 16 19	VIII
21	Madhapar	69 42 43	23 15 36	VIII
22	Sukhpur	69 36 05	23 14 10	VIII
23	Lodai	69 51 43	23 26 29	VIII
24	Gandhidham	70 08 45	23 03 56	VIII
25	Kandla	70 12 21	23 02 45	VIII
26	Radhanpur	69 44 40	23 19 03	VIII
27	Nakhtarana	69 15 03	23 20 02	VII
28	Naliya	68 50 09	23 16 05	VII
29	Khawda	69 43 03	23 50 59	VII
30	Mandvi	69 22 01	22 50 02	VII
31	Jamnagar	70 03 59	22 27 59	VII
32	Halvad	71 11 01	23 01 00	VII
33	Morvi	70 50 03	22 49 03	VII
34	Ahmedabad	72 54 50	23 25 09	VII, VI
35	Surendranagar	71 41 01	22 42 04	VI
36	Viramgam	72 02 02	23 06 59	VI
37	Rajkot	70 50 01	22 20 02	VI
38	Gandhinagar	72 41 09	23 12 58	VI
39	Surat	73 03 00	20 55 00	VI
40	Vadodara	73 29 56	22 30 02	VI
41	Broach	72 59 59	21 45 04	IV

Figures 2 and 3 caption (Continued)

Three storeys of a small portion of the building remained standing, seen in the photograph above, because of some partial attachment of stiff core of lift shaft to staircase. The lift shaft separated from the rest of the building. Torsion occurred due to discontinuity of horizontal and vertical configuration.

This RC framed structure suffered a damage of grade 5. This is a typical example where one should assign a low vulnerability class, in this case A (MSK-64 scale in IS 1893–2002), which represents an exceptionally low class for this type of structure. Poorly made structures in Gandhidham show similar damage and hence Gandhidham has been assigned intensity VIII.

Cranes and other heavy earth moving equipment were used to demolish the building. 300 bodies were already recovered from this area and four were taken out on third February, at the time of the visit. Two other similar buildings on the same street suffered the same fate.

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References

Biswas S K and Deshpande S V 1983 ONGC Tectonic map of Kachchh, (Kutch), Geological map series no 1A, Scale 1:253440, ONGC, DehraDun.

Bose P R, Sinvhal A and Bose A 2001 Traditional construction and its behaviour in Kutch earthquake, p 151–158. In *Proceedings of Workshop on Recent Earthquakes of Chamoli and Bhuj, May 24–26, 2001, Roorkee* (eds) H R Wason, A K Pachauri and V Prakash; Ind. Soc. of Earthquake Technology, 551p

IS:1893-2002 (fifth revision) *Indian Standard Criteria for Earthquake Resistant Design of Structures*, Bureau of Indian Standards, New Delhi, India.

Prakash V, Sinvhal A and Bose P R 2001a Effects of the Kutch Earthquake of 26th January, 2001 on Oil Industry, p 159–165. In: *Proceedings of Workshop on Recent Earthquakes of Chamoli and Bhuj, May 24–26, 2001, Roorkee* (eds) H R Wason, A K Pachauri and V Prakash; Ind. Soc. of Earthquake Technology, 551p

Prakash V, Joshi V H, Wason H R and Sinvhal A 2001b Damage observed in temples, prayer halls and community centers due to the Kutch earthquake of 26th January, 2001, p 407–421. In: *Proceedings of Workshop on Recent Earthquakes of Chamoli and Bhuj, May 24–26, 2001, Roorkee* (eds) H R Wason, A K Pachauri and V Prakash; Ind. Soc. of Earthquake Technology, 551p

Prakash V, Joshi V H and Wason H R 2001c Effects of the Kutch earthquake of 26th January, 2001 on municipal overhead tanks, ground reservoirs and pumping units, p 433–441. In: *Proceedings of Workshop on Recent Earthquakes of Chamoli and Bhuj, May 24–26, 2001, Roorkee* (eds) H R Wason, A K Pachauri and V Prakash; Ind. Soc. of Earthquake Technology, 551p

Prakash V, Joshi V H and Wason H R 2001d Effects of the Kutch earthquake of 26th January, 2001 on Gujarat electricity board substations, p 443–449. In: *Proceedings of Workshop on Recent Earthquakes of Chamoli and Bhuj, May 24–26, 2001, Roorkee* (eds) H R Wason, A K Pachauri and V Prakash, Ind. Soc. of Earthquake Technology, 551p

Prakash V, Sinvhal A, Bose P R, and Bose A 2001e Effects of the Kutch earthquake of 26th January 2001 on lifeline structures. In: *Abstract volume, International Conference on Seismic Hazard with Particular Reference to Bhuj Earthquake of January 26, 2001*, 3–5 October 2001, IMD, New Delhi.

Prakash V, Sinvhal A and Bose P R 2001f Oil industry and the Kutch earthquake of 26th January 2001, p 175–178. In: *Abstract volume, International Conference on Seismic Hazard with Particular Reference to Bhuj Earthquake of January 26, 2001*, 3–5 October 2001, IMD, New Delhi.

Saraf A K, Sinvhal A and Sinvhal H 2001 26th January 2001 Bhuj Earthquake: satellite data reveals earthquake induced ground changes and appearance of water bodies, p 207–215. In: *Proceedings of Workshop on Recent Earthquakes of Chamoli and Bhuj, May 24–26, 2001, Roorkee* (eds) H R Wason, A K Pachauri and V Prakash; Ind. Soc. of Earthquake Technology, 551p

Saraf A K, Sinvhal A, Sinvhal H, Ghosh P and Sarma B 2002 Satellite data reveals 26 January 2001 Kutch Earthquake induced ground changes and appearance of water bodies; *International Journal of Remote Sensing* **23** 9, p 1749–1756

Sinvhal A, Bose P R, Prakash V, Bose A, Saraf A K and Sinvhal H 2001a Damage, seismotectonics and isoseismals for the Kutch earthquake of 26th January, 2001, p 61–70. In: *Proceedings of Workshop on Recent Earthquakes of Chamoli and Bhuj, May 24–26, 2001, Roorkee* (eds) H R Wason, A K Pachauri and V Prakash; Ind. Soc. of Earthquake Technology, 551p

Sinvhal A, Bose P R, Bose A and Prakash V 2001b Damage observed to educational buildings due to the Kutch earthquake of 26th January, 2001, p 381–388. In: *Proceedings of Workshop on Recent Earthquakes of Chamoli and Bhuj, May 24–26, 2001, Roorkee* (eds) H R Wason, A K Pachauri and V Prakash; Ind. Soc. of Earthquake Technology, 551p

Sinvhal A, Bose P R, Bose A and Prakash V 2001c Damage observed to hospitals and medical facilities due to the Kutch earthquake of 26th January, 2001, p 389–397. In: *Proceedings of Workshop on Recent Earthquakes of Chamoli and Bhuj, May 24–26, 2001, Roorkee* (eds) H R Wason, A K Pachauri and V Prakash; Ind. Soc. of Earthquake Technology, 551p

Sinvhal A, Bose P R, Bose A and Prakash V 2001d Damage to railway bridge at Dholawa and railway station at Bhachau in Kutch earthquake of 26th January, 2001, p 399–406. In: *Proceedings of Workshop on Recent Earthquakes of Chamoli and Bhuj, May 24–26, 2001, Roorkee* (eds) H R Wason, A K Pachauri and V Prakash; Ind. Soc. of Earthquake Technology, 551p

Sinvhal A, Bose P R, Bose A and Prakash V 2001e Damage observed to Surajbari bridge due to the Kutch earthquake of 26th January, 2001, p 423–431. In: *Proceedings of Workshop on Recent Earthquakes of Chamoli and Bhuj, May 24–26, 2001, Roorkee* (eds) H R Wason, A K Pachauri and V Prakash; Ind. Soc. of Earthquake Technology, 551p

Sinvhal A, Bose P R, Prakash V, Bose A, Saraf A K and Sinvhal H 2001f Isoseismals for the Kutch earthquake of 26th January 2001, p 179–182. In: *Abstract volume, Inter-*

national Conference on Seismic Hazard with Particular Reference to Bhuj Earthquake of January 26, 2001 3–5 October 2001, IMD, New Delhi.

Sinvhal A, Bose P R, Bose A and Prakash V 2001g Multistorey buildings and the Kutch earthquake of 26th January 2001, p 183–187. In: *Abstract volume, International Conference on Seismic Hazard with Particular Reference to Bhuj Earthquake of January 26, 2001* 3–5 October 2001, IMD, New Delhi.

Sinvhal A and Prakash V 2002 The Kutch earthquake of January 2001 and heritage buildings and monuments. In: *Abstract Volume, Conference on Strategy and Methodology for Conservation of Heritage Buildings*, CBRI, Roorkee, April 4–5, 2002.