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DAMAGE REPORT OF THE BIHAR NEPAL EARTHQUAKE OF AUGUST 21, 1988

Rajiv DUGGAL (I)
and
Nobuhiko SATO (II)

INTRODUCTION

The strong earthquake of August 21, 1988 struck near the epicentral area of the devastating tremor of 1934. The quake was felt in distant Indian states as Rajasthan, Madhya Pradesh and the North-Eastern states. However, damage was reported in the state of Bihar and neighbouring Nepal. The damage was predominantly concentrated over a radius of 150 km from the epicentre, but the tremors were felt as far as New Delhi in the west and Shillong in the east (Figure 1). In New Delhi, located about 1200 km north west of the epicentre, an intensity of III on the Modified Mercalli Scale was recorded.

The reason for the damage being so extensive, was that the quake struck close to thickly populated areas. Morever, the alluvial soil of the Indo-Gangetic plain makes the region particularly vulnerable during earthquakes. The quake caused considerable loss of life and property in Nepal and India (Table 1).

In India, North Bihar was the most severely affected region, with reports of some damage in the neighbouring states of West Bengal and Sikkim. The quake affected 18 districts of Bihar, the worst affected being that of Dharbhanga, Madhubani, Saharsa, Munger

(I) Graduate Student, Institute of Industrial Science, University of Tokyo
(II) Research Assistant, ditto

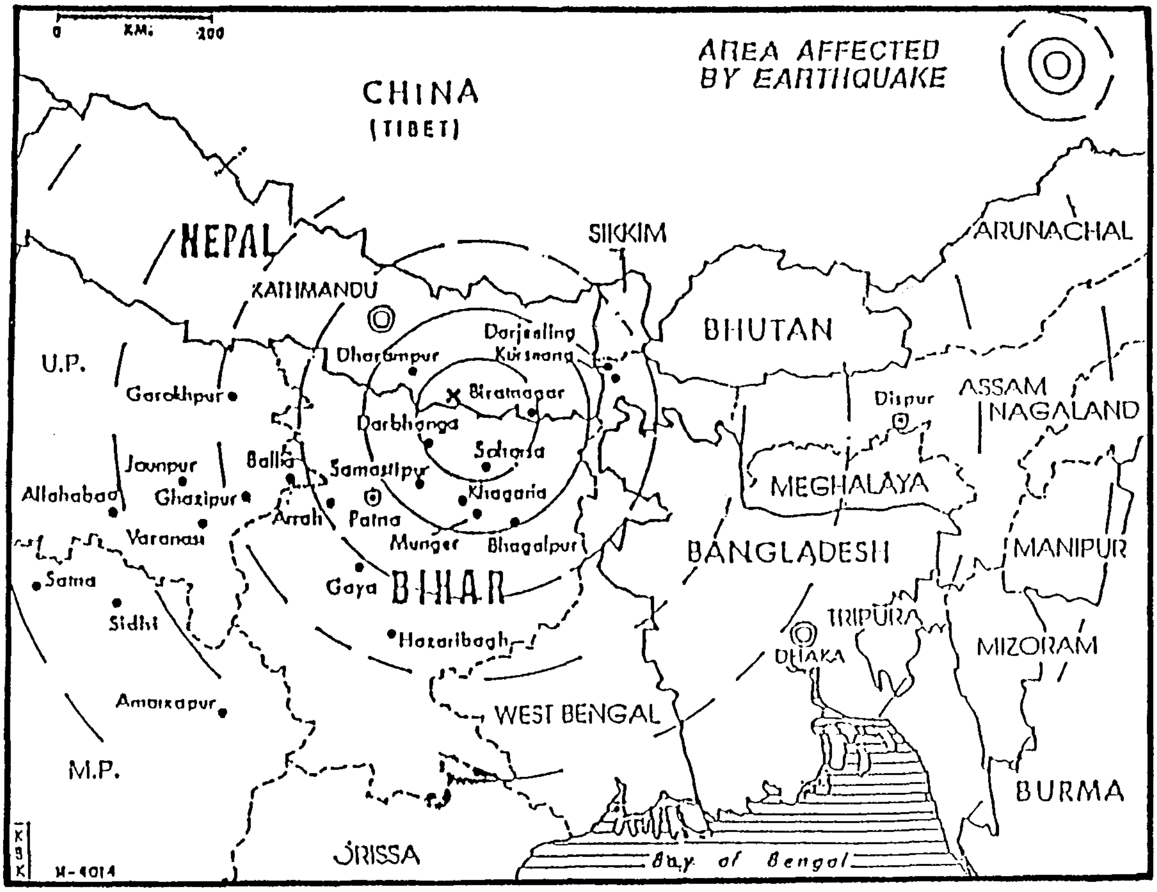

Fig. 1 General Affected Areas in India and Nepal

and Khagaria (see Figure 2 and Table 2; note that the districts are numbered in Figure 2 in the order of their appearance in Table 2). The damage in India was light to moderate, with most modern reinforced structures including bridges, water tanks etc. remaining unscathed. The quake affected mainly old and poorly built houses and masonry buildings already weakened by the previous 1934 strong tremor.

In Nepal the quake left over 700 people dead and many more injured and damage worth millions of rupees. Panchtar, Ilam, Dhankuta, Sunsari, Tehrathum and Udayapur, were worst affected districts in the eastern region whereas Sindhuli suffered maximum damage in the central region (see Figure 3 and Table 3). The immediate aftermath of the disaster was myriad: the formation of small craters in Udayapur district, the drying up of wells in some places, fields strewn with sands in some places, the swelling of streams etc. besides the flattened houses and homeless people.

GEOLOGICAL AND TECTONIC BACKGROUND OF THE REGION

The epicentral area of the Bihar-Nepal Earthquake lies in the Gangetic alluvium. Figure 4 shows the basin of the Indo-Gangetic plain. The upper layers of the alluvium in North Bihar have been laid down by rivers flowing in the SE direction. The alluvial terrain of the lower Ganga plain consists of a thick pile of unconsolidated Quarternary sediments comprising multicyclic, fining upward sequence of sand, silt and clay in varying proportions. Further north towards the foothills of the Himalaya (in Nepal), the sediments reportedly become gradually coarse grained to form the boulder-cobble-pebble-gravel-sequences. It is a flatish alluvial terrain having an over all southerly slope and is devoid of any significant relief feature. The sand dykes in this region reach almost to the surface, while some have already crossed the land surface to erupt as sand blows. This phenomena was commonly reported during the 1934 Bihar-Nepal earthquake and also occurred during the present earthquake.

The Himalayan range is located on the active seismic zone

Table 1: Summary of Bihar-Nepal Earthquake of 1988

Date	August 21, 1988		
Time	4 54' 35.3'' (Local Nepal Time)		
Magnitude	6.7 (Dept. of Mines and Geology, Kathmandu) 6.5 (New Delhi, India) 7.1 (Peking, China) 6.6 (France)		
Epicenter	26.7N, 86.5E (D.M.G., Kathmandu) 26.4N, 86.6E (New Delhi, India)		
Focal Depth	20 km (New Delhi, India)		
	In India	In Nepal	
Killed	282	704	
Injured	3766	Serious 452	Minor 683

ranging from Java-Burma-Himalaya-Iran-Turkey and Europe where many damaging earthquakes have occurred in the past (Figures 5 and 6). Active seismicity in the Indian subcontinent is located mostly around the boundary of the Indo-Australian plate with the Eurasian and Chinese plates. Continuous grinding of the continental plates imparts geologic unstability to the region. The prominent feature exhibiting strong seismicity in this region is the Himalayan arc where the total energy release is about 2% of the global annual earthquake energy. The earthquake foci are mainly located along the southern margin of the arc. Density of earthquake occurrences falls off gradually towards the north across the Tibetian plateau and China, but rather abruptly across the peninsular India to the south. The most active regions of the Himalayan arc are its northern and eastern syntaxes. The recent earthquake was located in the north-eastern portion of the Himalayan arc.

A most devastating earthquake of magnitude M=8.4 (Richter, 1958) occurred on January 15, 1934 (epicentre 26.6 N, 86.8 E) at Bihar-Nepal border region, very close to the epicentral area of the present earthquake. This quake was felt over an area of 4,920,000 sq. km in India, Nepal and Tibet. In the meizoseismal region the earthquake caused great destruction, created numerous fractures, landslides, a 250 km long and at places up to 60 km wide slump belt and took a toll of 11,000 human lives.

RECONNAISSANCE

The magnitude of the Bihar-Nepal earthquake of 1988 was about 6.7. The earthquake caused considerable loss of life and different degrees of damage to various dwellings in the region. The most common forms of construction, consisting of brick masonry in cement and mud mortar suffered very extensive damage. The zone of major damage was influenced by subgrade conditions, which consisted of alluvium.

The earthquake caused no damage to reinforced concrete water tanks located very close to the epicentre. Also tall buildings in the Patna city (160 km from epicentre) were left undamaged, though many low rise houses suffered various degrees of damage. There was no report of damage to water supply, though electicity was cut off immediately after the quake. Railway services were disrupted for three days due to moderate damage to a girder bridge (100 km from the epicentre).

Figure 7 shows the location, from the epicentral area, of the cities/towns visited by our survey team. Most of the buildings seen by us, in India, were those under the supervision of the Bihar Public Works Department (BPWD). Table 4 gives an abstract of the number of BPWD buildings damaged in each of the affected districts and the estimated cost to repair them (taken from the preliminary report prepared by the BPWD). Due to paucity of time only few earthquake affected areas in Nepal could be visited.

The absence of damage to moderately tall structures like water tanks etc. in areas very close to the epicentre, with extensive damage to one and two storeyed structures even at distances up to 150 km from the epicentre, suggests to the prominence of short period components of ground motion. However, since no instrumental records of strong ground motion were obtained, definite conclusions cannot be reached at.

One characteristic feature of this earthquake is that it caused extensive damage to houses located at a distance of about 150 km (e.g. Munger in Bihar, India and Bhakatpur, near Kathmandu, Nepal) from the epicentre in nearly opposite direction. This damage pattern is consistent with the damage caused in the previous strong tremor of 1934. Such effects point to the local amplification of ground motion. According to Richter, the presence of a ridge of Archean quartzite emerging through the alluvium was responsible for heavier damage in Munger during the previous strong tremor of 1934. Similarly, in Kathmandu valley, the heavy damage was on unconsolidated ground during the 1934 tremor. Similar local ground effects cannot be ruled out for the present event.

Buildings: Unreinforced masonry bearing wall structures proved inadequate to resist the lateral forces imposed upon them by the

Photo 1. Collapsed boundary wall of Girls School, undamaged RC house in back view (Dharbhanga)

Photo 2. Old Medical Boy's Hostel (Dharbhanga)

Photo 3. Rear view of Surgical Hospital (Dharbhanga)

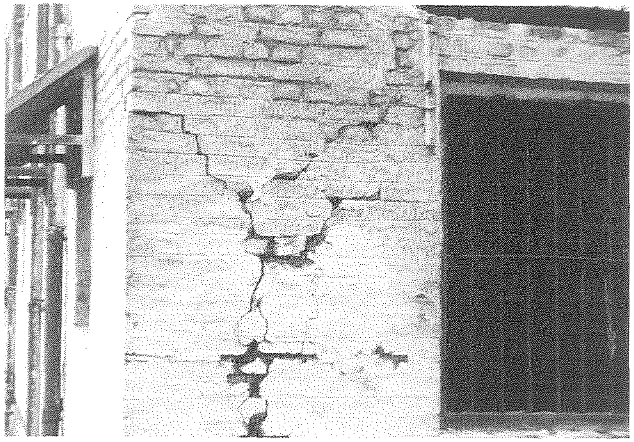

Photo 4. Damaged Jila School (Dharbhanga)

Photo 5. Cracked arch of same building

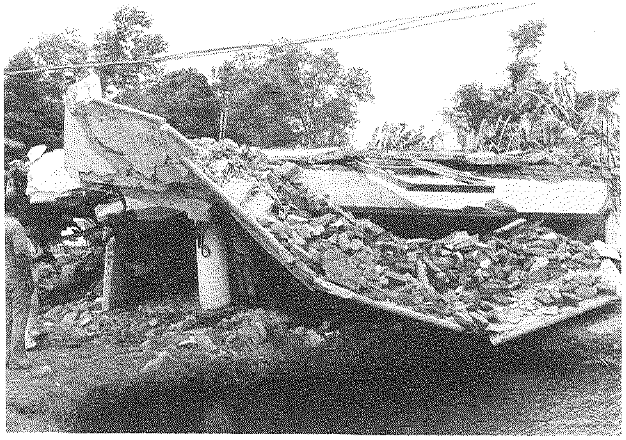

Photo 6. Collapsed I. T. I. Building (Dharbhanga)

Photo 7. Crushed column of same building

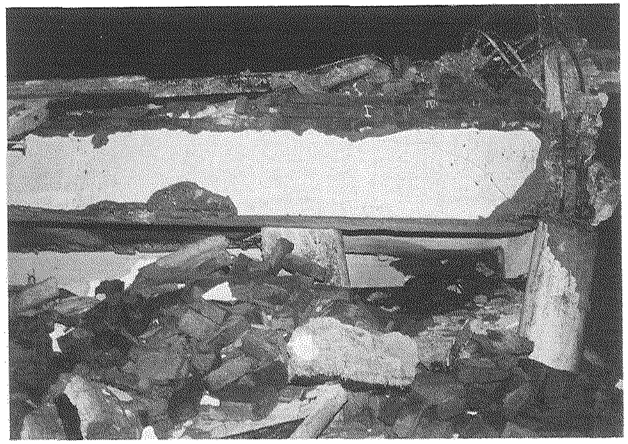

Photo 8. Undamaged beams of the same building

Photo 9. Damaged floor due to soil liquefaction

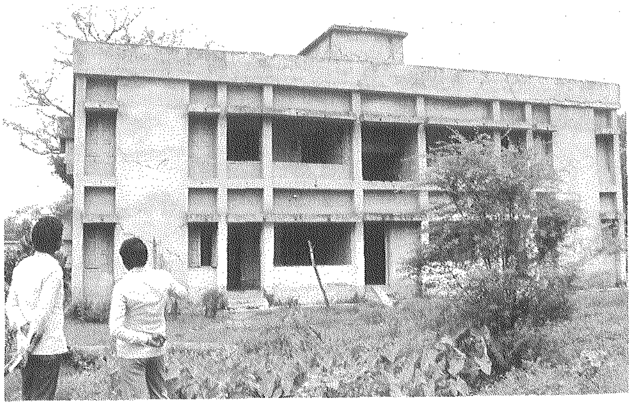

Photo 11. Apartment Building (Samastipur)

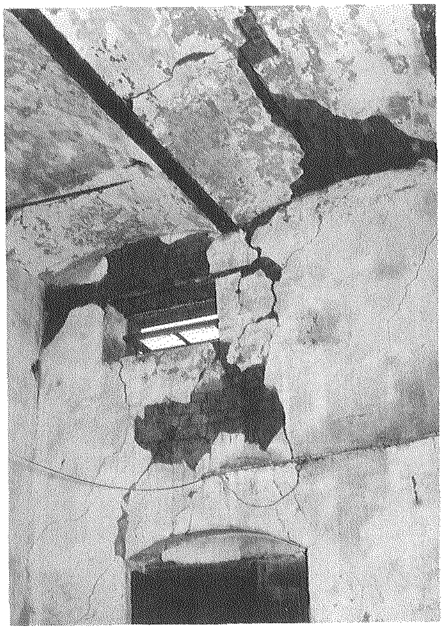

Photo 10. Damaged Roof of Clinic Building (Sakira)

Photo 12. Apartment Building (Samastipur)

earthquake. Many of them were so badly damaged as to make repair economically unfeasible if not impossible. Many mud-built houses suffered almost complete collapse, due to the inherent weakness of the material in tension and shear and low compressive strength.

Of the reinforced concrete framed structures, those which were designed without regard to lateral forces suffered damage. The most dramatic of these was the Indian Training Institute building, which collapsed (Photos 6 to 8). It was reported that with one exception, the rest remained standing.

The principle of relative rigidities assures that the resisting elements of a structure, subjected to lateral load, share the load in proportion to their rigidities. The most rigid element assumes the greatest burden and if it is incapable of assuming it, failure results. Examples of this are seen in the Samastipur apartment buildings (Photos 11 and 12).

The task of repair and rehabilitation is enormous, with the collapse of many houses, especially in Dharan, Nepal, where 70% of the mud houses were said to be damaged. The damage pictures of buildings in Dharan, show one noteworthy feature. Many houses with inclined tin roof, supported sometimes on wooden planks, are seen left unscathed next to the rubble from collapsed masonry houses (Photos 16 to 22). The total damage by the quake to public and private property, in Nepal, is put at about Rupees 530 million (approximately 5 billion Yen), out of which 40% occurred in Dharan.

Ground Liquefaction: In many areas near the epicentral region sand erupted along with water, like a volcano, up to a height of 6 feet. Nearby houses were badly damaged, with the bursting of the floors under pressure from rising sand (Photo 9 and 23). It is said that here many wells became filled with sand and the water turned reddish. Also some hand pumps which earlier were dry, had water flowing in them after the earthquake.

Railway facilities: Figure 8 shows the railway network in the earthquake affected region. The girder bridge over river Gandhak,

Photo 13. A damaged house (Bhakatpur)

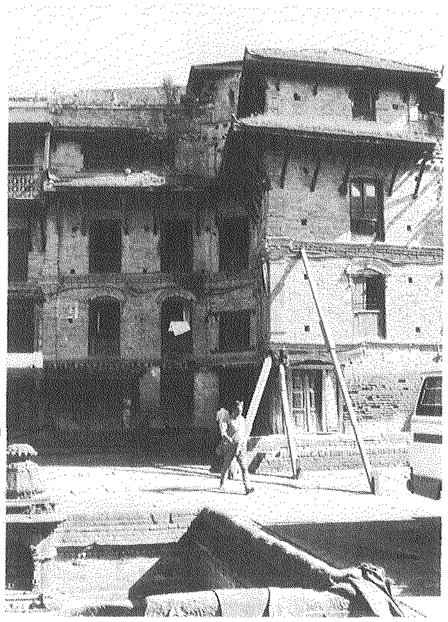

Photo 14. View of 4 storeyed brick houses (Bhakatpur)

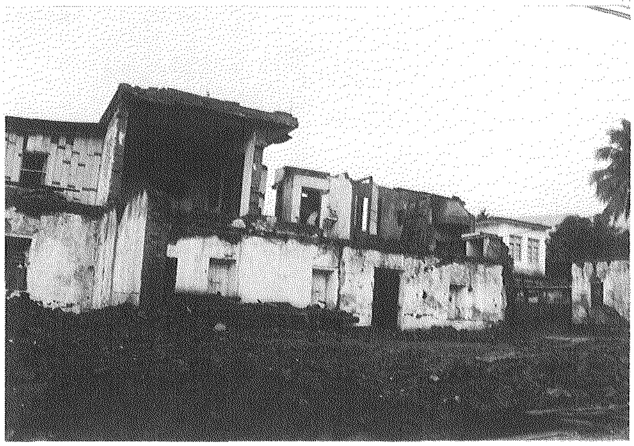

Photo 15. A damaged house (Dharan)

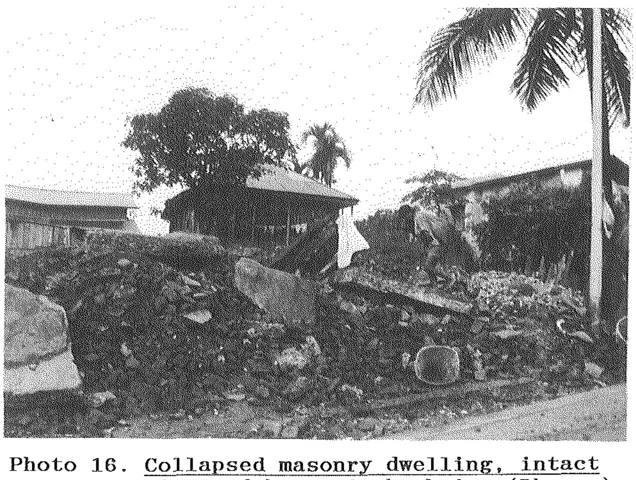

Photo 16. Collapsed masonry dwelling, intact tin roof house in backview (Dharan)

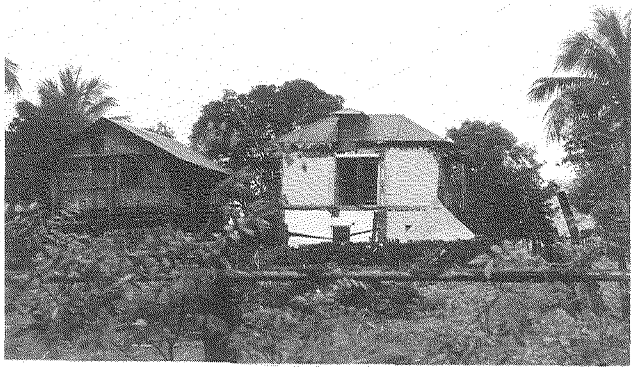

Photo 17. Undamaged wooden frame house (Dharan)

Photo 18. Collapsed masonry of school building, intact RC frame in back view (Dharan)

Photo 19. A house tilted after the quake (Dharan)

Photo 20. Another damaged dwelling (Dharan)

near Samastipur, was damaged by the quake. The rocker bearing was damaged resulting in the sinking of the deck by about 30 cm. Sinking of railway tracks was reported in the Saharsa-Madhepura section, but were repaired within three days.

Embankments: The river embankment over Butahi Balan in Madhubani district (marked Ⓐ in Figure 8) and the western and eastern embankments of river Kosi developed longitudinal cracks.

Bridges: We could not find any severe damage on bridges, located on our reconnaissance route. A modern reinforced concrete bridge, over river Ganges, at about 150 km south-west of the epicentre remained undamaged. In Nepal, a suspension bridge was said to be damaged. Also certain instances of slight settlement of approach were also observed over there.

NATURE OF DAMAGE TO BRICK MASONRY HOUSES

The brick masonry buildings suffered considerable damage during the earthquake. These buildings are susceptible to severe damage due to the creation of the tensile and shearing stresses in the masonry walls. The main causes for damage to such buildings are the heavy weight and very stiff structural elements, very low tensile and shear strength due to poor mortar, weak connection between the walls and roof/wall. Stress concentrations at window/door openings also result in damage to such structures. Arches across the openings are badly damaged due to the loss of their end thrust under inplane shaking of walls.

The following are the main ways in which masonry buildings have been damaged by the recent earthquake:

1)Horizontal cracks in the wall at the ceiling/lintel level: Horizontal cracks develop in regions of non-homogeneous material, under vibratory motion. Such cracks were seen at the concrete roof and masonry wall intersection.

2)Horizontal/diagonal cracks in the wall at sill or near the floor level: The unsymmetry due to the unbalanced size and locations of the openings in the wall results in the development of

Photo 21. A damaged house under reconstruction (Dharan)

Photo 22. Undamaged traditional houses supported on wooden planks (Dharan)

Photo 23. Soil liquefaction Site (Nepal)

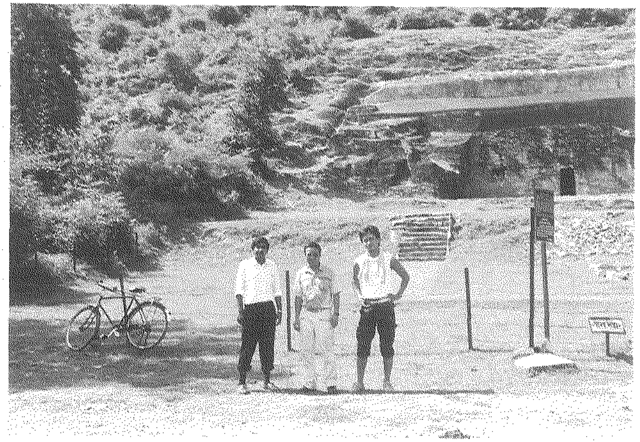

Photo 24. Members of the Survey Team

horizontal/diagonal cracks beginning from the openings (Photo 4).

3)Vertical cracks in load bearing walls at the junction of walls: Such cracks occur when the wall fails in bending due to the loading in direction transverse to the plane of the wall. Tension cracks occur vertically at the centre, ends or corners of walls.

4)Single/multiple cracks in the masonry arch: The crack starts at or near the crown of the arch and propogates upwards in the masonry wall (Photo 5).

5)Vertical or diagonal cracks in the walls above the masonry arch: Here, though the arch itself remained intact, the masonry walls developed diagonal cracks. Such failure occurred either through the pattern of the joint or diagonally through the masonry units, depending on the relative strength of the brick unit and the binding mortar.

6)Distress in Jack arch roof: These are brick masonry arch roofings supported on I beams. They have spans of about 1.0-1.5 m and a rise of about 15 cm. Loosening of brick units, rendering them susceptible to collapse, occurred in many places (Photo 10).

7)Diagonal cracks resulting in masonry total failure: Failure due to racking shear is characterized by diagonal cracks which could be due to diagonal tension/compression.

CONCLUDING REMARKS

Though the damage to civil engineering structures was conspicuous by its absence, traditinal dwellings in the region were extensively damaged. Some areas of relatively higher damages, suggest to the non-uniform behaviour of the ground supporting them. This phenomena points to the importance of geological and topographical effects, which considerably alter the damage pattern in the affected area. The design of earthquake resistant low-cost rural dwellings is a complex subject with large socio-economic dimensions. In this earthquake there have been some structures which stood up without damage amongst some severely damaged ones. It is hoped that they will provide useful guidelines to the engineers and authorities, in developing effective earthquake resistant low-cost rural dwellings for the region.

The reconnaissance survey of the affected area was conducted by the authors and Toshio Fukui (Research Assistant, Laboratory of Urban Safety Planning) from September 11 to 25, 1988. They are most grateful for the wholehearted cooperation of Dr A.S. Arya, Dr. B.V.K. Lavania, Dr. V.M. Joshi and other faculty members of the Dept. of Earthquake Engineering, University of Roorkee in making this visit a fruitful one. We deeply appreciate the efforts of Engineer-in-Chief, Mr. D.C. Jha and other officers of the Bihar Public Works Department, who helped make our survey a success. We also thank Mr. V. Ramachandran, President, Indian Society for Earthquake Technology and Dr. S.B. Sinha, Counsellor (Science and Technology), Embassy of India, Tokyo for their invaluable help.

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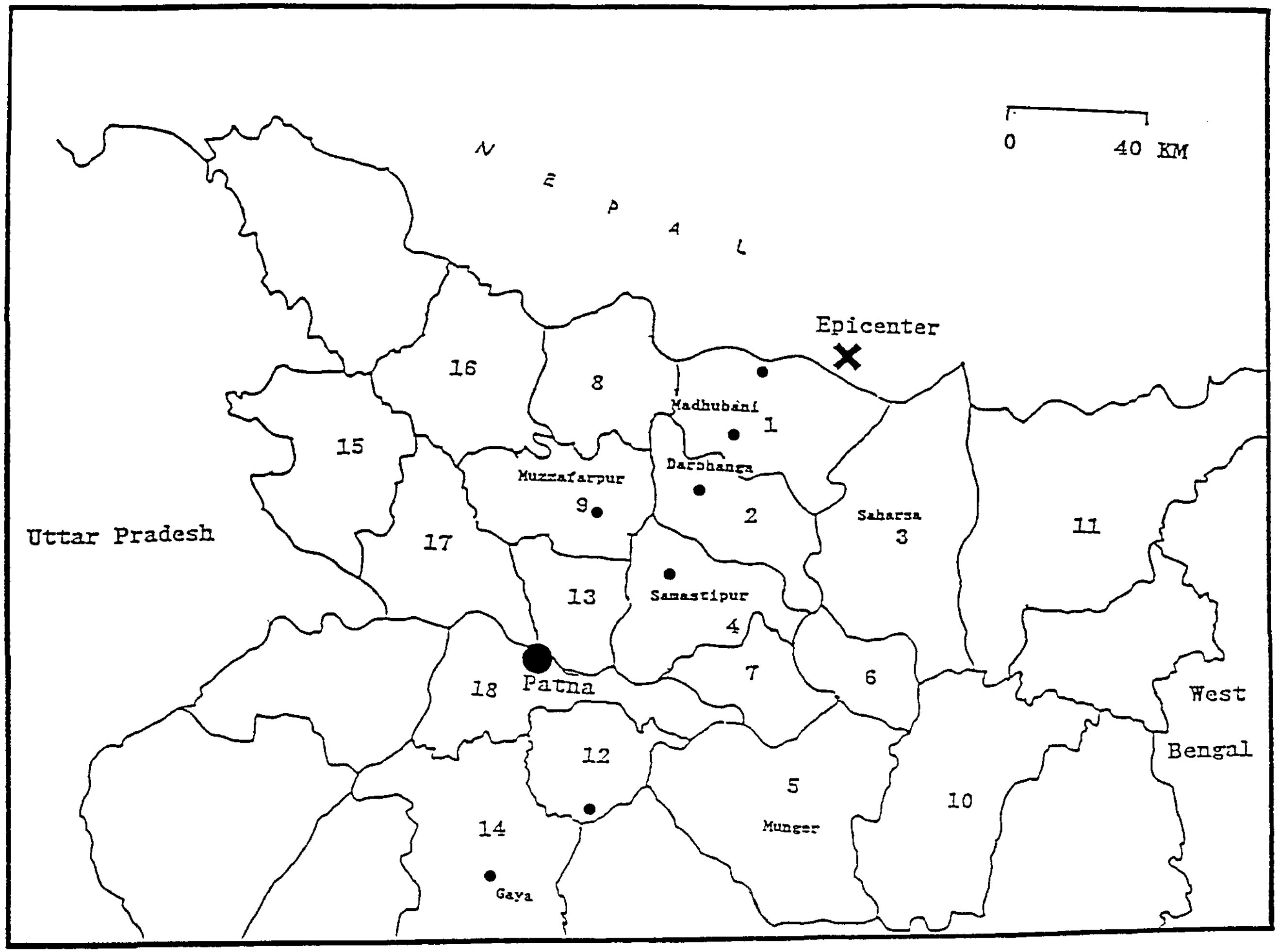


Fig. 2 Earthquake Affected Districts in Bihar State

Table 2: Districtwise damage in Bihar State

No.	District	Population	Death	Injured	Number of Houses Damaged		
					Mud Built	Brick Built	Total
*1.	Madhubani	2325000	99	659	21747	16686	38443
2.	Dharbhanga	2008000	83	992	25706	27178	52884
3.	Saharsa	1989000	21	435	10955	7367	18333
4.	Samastipur	3161000	21	158	4217	1248	5465
5.	Munger	2546000	16	932	18210	10230	28440
6.	Khagaria	768000	9	238	940	588	1528
7.	Madhopura	964000	9	30	295	155	450
8.	Sitamarhi	1932000	6	75	836	963	1799
9.	Muzaffarpur	2357000	5	19	112	-	112
10.	Bhagalpur	2621000	3	24	29	-	29
11.	Purnea	3595000	3	17	1152	8	1160
12.	Nalanda	1641000	1	20	60	34	94
13.	Giridth	1731000	1	1	1	-	1
14.	Jehanabad	800000	1	-	-	-	-
15.	Gopalganj	1362000	-	3	-	-	-
16.	Sahebganj	1079000	-	5	1	-	1
17.	Saran	2084000	-	3	-	-	-
	Total	69914732	282	3766	84716	64618	149334

*Numbers in this Table correspond to those in Fig. 2.

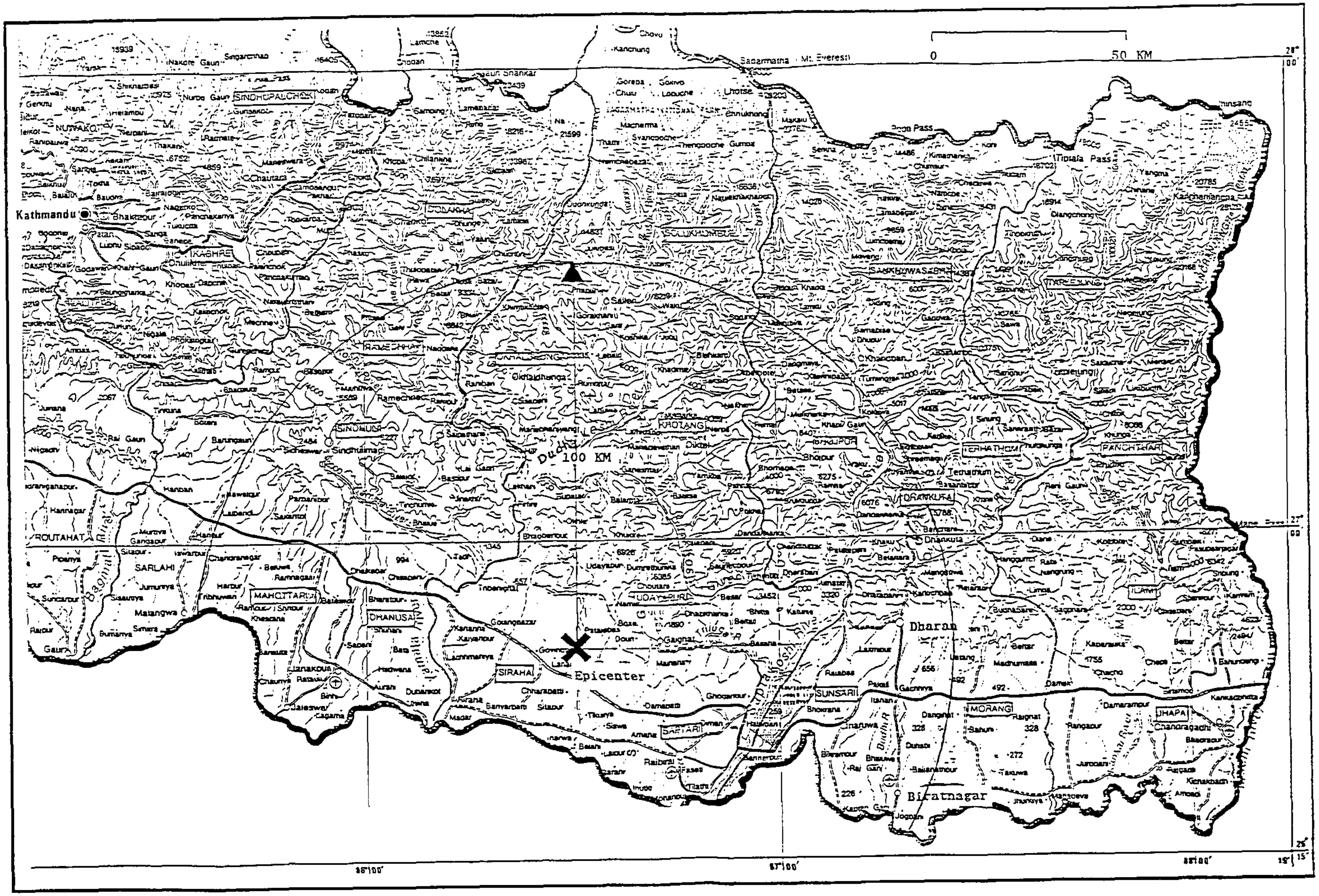
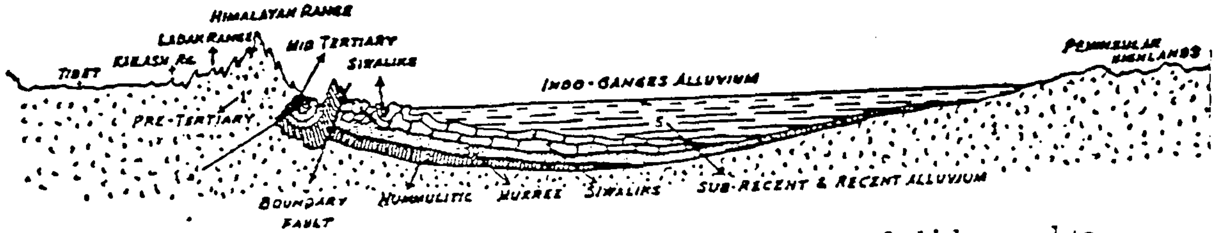


Fig. 3 Earthquake affected districts in Nepal

Table 3: Districtwise Casualty Figures in Nepal '
(taken from newspaper 'The Rising Nepal')

District	Death	Serious Injuries	Minor Injuries
Sunsari	132	18	250
Panchthar	96	44	14
Dhankuta	90	88	-
Udaipur	80	34	66
Ilam	73	30	24
Tehrathum	65	56	31
Morang	30	28	109
Khotang	26	21	23
Sindhuli	25	33	10
Sankhuwasabha	19	15	9
Bhojpur	14	22	18
Saptari	11	18	27
Siraha	8	13	2
Okhaldhunga	7	10	16
Bhakatpur	7	1	29
Jhapa	4	5	3
Kavre	4	2	6
Taplejung	3	5	1
Dhanusha	2	1	3
Dolkha	2	-	-
Ramechhap	2	-	-
Sindhupalchowk	2	-	1
Mahottari	1	-	-
Lalitpur	1	1	9
Solukhumbu	-	1	3
Bara	-	-	2
Kathmandu	-	6	27
Total	704	452	683



The basin of the Indo-Gangetic plain, the floor of which sagged to receive copious sediments mainly from the rising Himalaya.
(After D. N. Wadia, F.R.S.)

Fig. 4 The basin of Indo-Gangetic Plain

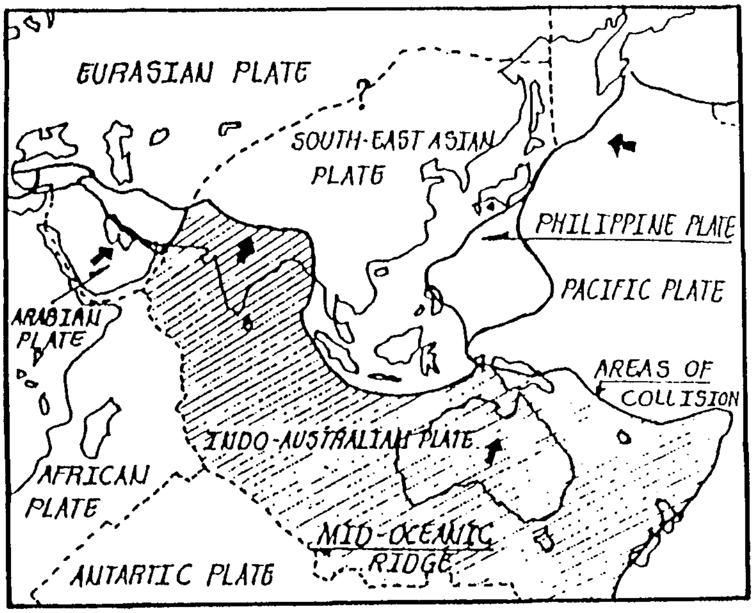


Fig. 5 Main Plates around the Himalaya

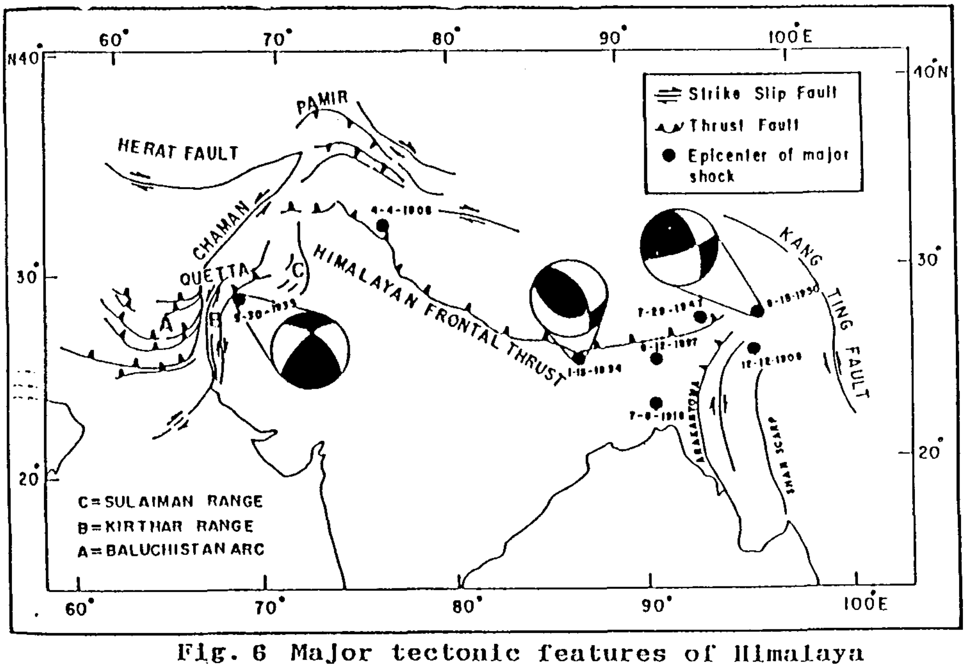


Fig. 6 Major tectonic features of Himalaya and nearby regions

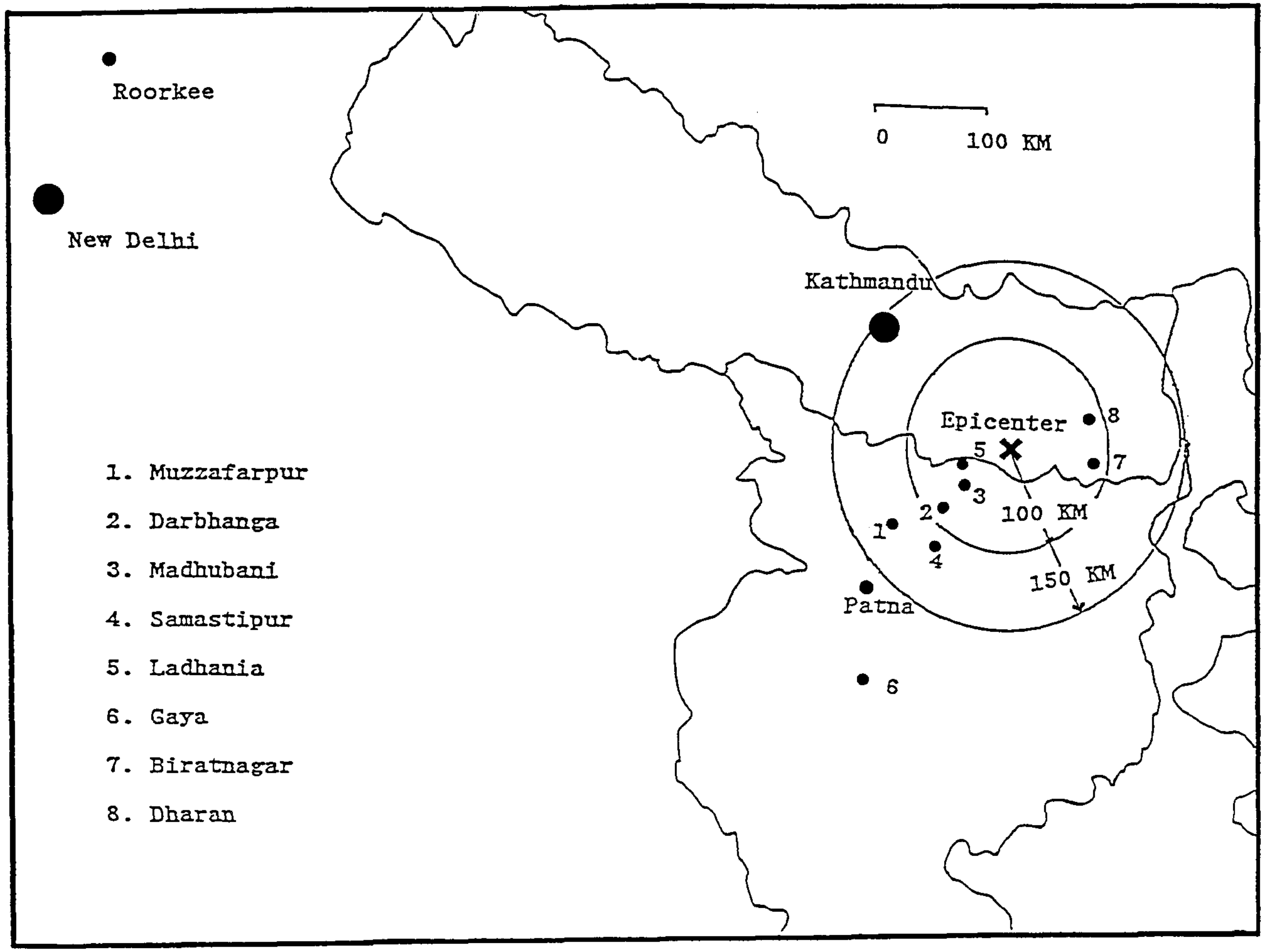


Fig. 7 Location of cities/towns visited

Table 4 : General Abstract of Damage to BPWD Buildings
(Note: Total Cost=1016 Million Yen
Equivalent Cost in Japan: 11 Billion Yen
{assuming living cost in Japan is 10 times})

District	No. of damaged houses				Estimated Cost of Repair/Rebuilding (Million Rupees)			
	Minor damage	Major damage	Collapse	Total No.	Minor damage	Major damage	Rebuilding Replacement	Total Cost
Darbhanga	79	42	16	137	7.7	4.2	19.6	31.5
Madhubani	122	21	25	168	4.7	2.3	8.5	15.5
Begusarai	14	27	8	49	0.3	4.1	1.7	6.1
Saharsa	69	23	12	104	1.8	2.2	2.0	6.0
Madhepura	60	17	1	78	1.6	1.4	0.3	3.3
Samastipur	8	31	1	40	0.2	2.6	0.3	3.1
Khagaria	69	5	-	74	2.6	0.3	-	2.9
Purnea	3	5	-	8	0.3	1.2	-	1.5
Muzaffarpur	38	2	1	41	0.4	0.3	0.2	0.9
Sitamarhi	9	-	-	9	0.5	-	-	0.5
Munger	58	63	25	146	3.5	8.0	5.0	16.5
Bhagalpur	74	45	3	122	4.6	4.8	0.5	9.9
Patna	100	6	-	106	2.4	0.3	-	2.7
Gaya	12	2	-	14	.06	0.7	-	0.76
Total	715	289	92	1096	30.66	32.4	38.1	101.16

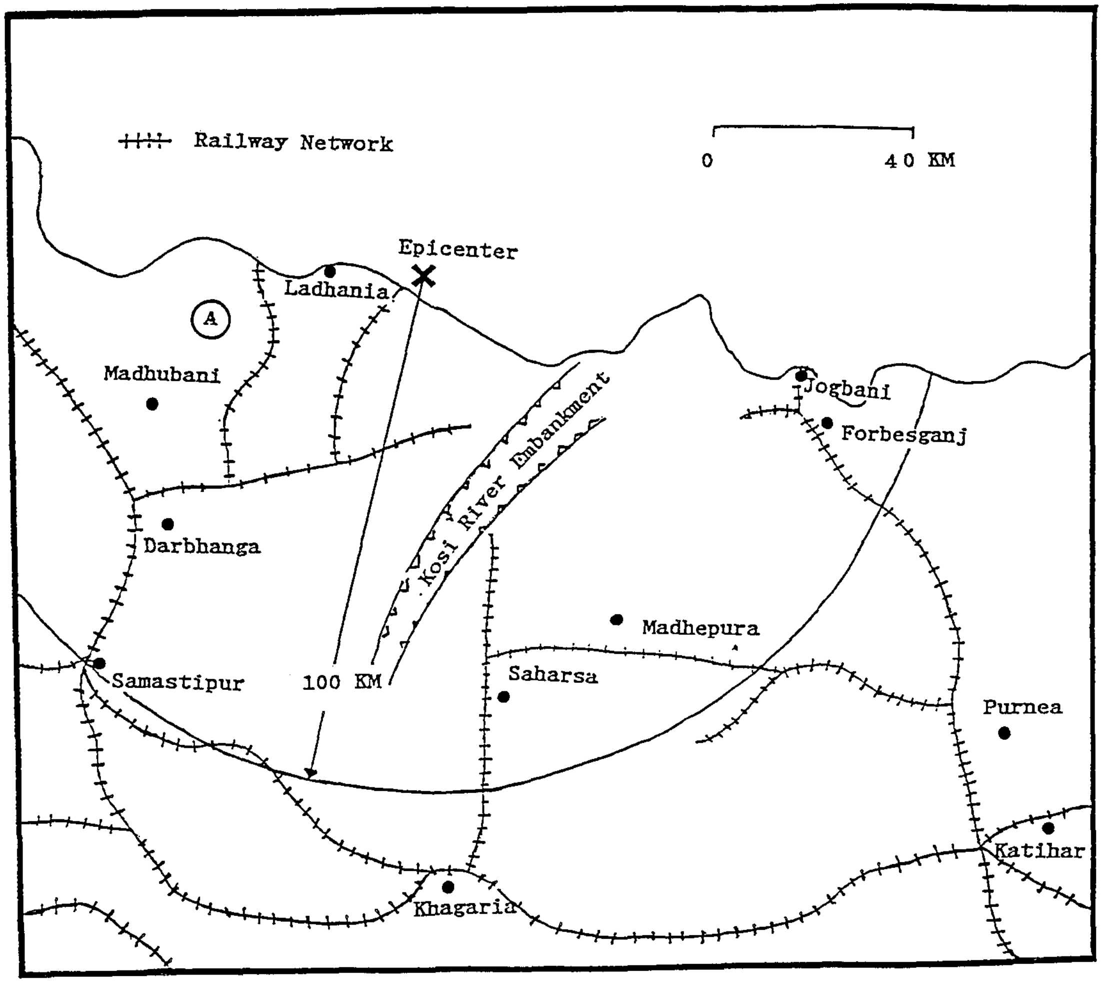


Fig. 8 Railway network and River embankments in the affected area in India