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Bihar-Nepal Earthquake of 15 January 1934: Isoseismals and Damages

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ABSTRACT The damage due to 1934 M8.4 Bihar - Nepal earthquake is described in short from Dunn et al. (1939) and Rana (1935, as quoted by Pandey and Molnar 1988). The earthquake was disastrous in north Bihar and southern Nepal. Magnitude 8.4 is most commonly used in the literature and is accepted. The epicentre 27.6^0 N 87.1^0 E given by USGS near Tibet border is most acceptable from the seismotectonic model. About 16,000 persons lost life in India (7,253) and Nepal (8,519). Intensity X was assigned in three areas on Rossi-Forel scale (corresponding to XII of Modified Mercally and MSK scales denoting total destruction). Largest isoseismal X area is a ESE trending 120 km x 30 km belt in north Bihar from east of Motihari through Sitamarhi to Madhubani. The other two isoseismal X areas are small: one south of Kathmandu from Patan to Bhaktapur and the other in and around Monghyr along the Ganges.

Keywords: Bihar-Nepal 1934 earthquake, damages, Isoseismals, Intensity

1. Introduction

A great earthquake is expected in Himalaya, hence, there is interest in knowing damage potential of such an earthquake. Arya (2013) has created a damage Scenario under hypothetical recurrence of 1934 earthquake intensities in various districts in Bihar. The damage due to 1934 M 8.4 Bihar - Nepal earthquake is described in detail by Dunn et al. (1939) mostly in India and some parts of Nepal and Rana (1935, as recompiled by Pandey and Molnar 1988) for Nepal. At some locations in India data of Nasu (1934) has also been used. As these publications are not readily available, this paper gives short description from them. Magnitude and locations given by different agencies show large differences. Justification for their most acceptable values is given.

2. The Parameters: Magnitude and Location

Magnitude given for 1934 earthquake is 8.3 by Gutenberg and Richter (1958), 8.4 by Richter (1954) as well as Duda (1965). Sapkota et al. (2013) assign M_w 8.2. Magnitude 8.4 is most commonly used in the literature and may be accepted. For the 1934 earthquake, USGS gives the epicentre 27.6^0 N 87.1^0 E near the Tibet border which is most acceptable. The relocated epicentre by Chen and Molnar (1977) is similar (27.55^0 N 87.09^0 E). Gutenberg and Richter give the epicentre 26.5^0 86.5^0 which is 100 km south of USGS epicentre and south of India-Nepal border and Seeber et al. (1981) give the epicentre 26.75^0N 86.7^0E which is 25 km NE of the epicentre by G-R and lying on Main Frontal Thrust. These locations are probably influenced by highly-damaged area in India (Figs. 1 and 2). Based on the intensity survey of Rana (1935), Pandey and Molnar (1988) and Molnar and Pandey (1989) argue that the 1934 epicentre could be in northern Nepal. The isoseismals for 1934 earthquake shown in Figs. 2 and 3 are from Dunn et al. (1939). Intensity was assigned on Rossi-Forel scale (I to X), intensity X

corresponding to XII of Modified-Mercally or MSK scales denoting total destruction. Rana (1936) as quoted by Pandey and Molnar (1988) described extensive damage in Nepal from India border up to latitude 27.5^{0}N, close to epicentre. Intensity VIII is assigned to this area. Molnar and Pandey (1989) infer thrust faulting from the first motion data.

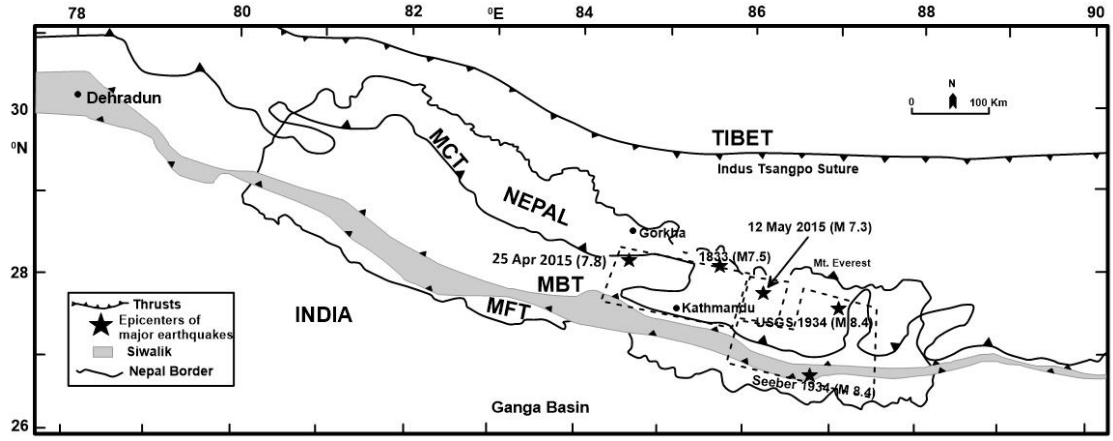


Fig. 1. Major thrusts and epicentres of the major earthquakes of Nepal since 1833 and possible rupture zones of 1934 (Mw 8.4), April 2015 (Mw 7.8) and May 2015 (Mw 7.3) earthquakes. Rupture areas are estimated from seismic moment, aftershock zone and seismotectonic considerations. The 1934 rupture inferred by Sapkota et al. (2013) extends more westwards from USGS epicentre than eastward; extending south of May 2015 rupture zone and up to MFT in a nearly pear shape. The shape taken here is rectangular, matching with the shape of aftershock zones of April and May 2015 earthquakes.

3. Rupture Areas of Some Large Earthquakes in Nepal

From the most accepted seismotectonic model of the Himalaya and also what has happened during the 2015 Gorkha, Nepal earthquake, it is believed that the large earthquakes originate at the Main Himalayan thrust near the Tibet border (Zilio et al. 2020) and the range of extension of rupture southward defines their magnitude (Bilham et al. 2001). Rupture for the 2015 Mw 7.8 earthquake was limited up to MBT and for great earthquakes of M > 8 like the 1934 earthquake, it most likely extends further south to Main Frontal thrust (MFT) lying close to Bihar-Nepal border. Sapkota et al. have found evidence of surface rupture for a length of 150 km near MFT. They dated the deformation in the same stretch of MFT corresponding to great 7 Jan 1255 earthquake that had destroyed Kathmandu and mortally wounded the Nepalese King Malla. However, Wesnousky et al. (2018) discount these investigations and say that no clear rupture evidence is seen near MFT.

Possible rupture zones of 1934 (Mw 8.4), April 2015 (Mw 7.8) and May 2015 (Mw 7.3) earthquakes are shown in Fig. 1. Rupture areas are estimated from seismic moment, aftershock zone and seismotectonic considerations. The rupture area by 3D rupture modelling for 2015 earthquake (Polet and USGS website reports) matches with the aftershock distribution. Longitude 86.1^{0}E is roughly the boundary between aftershocks (until August 2015) of April 25 and May 12 earthquakes. For the 1934 earthquake, rupture extends more towards west than east of USGS epicentre as can be inferred from most damaged areas in Nepal. The 1934 rupture inferred by Sapkota et al. (2013) covers most of the Intensity VIII area from USGS epicentre to India border in the longitude range 85.8^{0}E - 87.5^{0}E and from Main Himalayan Thrust near the epicentre to Main Frontal Thrust near the India border. They define a near-pear shaped area with its top near the epicentre. As the rupture zones and aftershock zones for the April and May 2015 earthquakes is rectangular, we define rupture zone of 1934 earthquake in the form of two adjoining rectangles.

It does not overlap the May 2015 rupture, but extends south of it. On the eastern side rupture zone may extend to east of Dhankuta as beyond that there is much less damage.

4. Description of Damages

The Bihar-Nepal earthquake of 15 January 1934 (Time between 2:13 and 2:14 PM) was disastrous in north Bihar and Kathmandu valley. The earthquake caused extensive landslides in the Nepal Himalayas in the latitude range 27° - 28° N. Within 3 minutes Monghyr and Bhaktapur (Bhatgaon) were in ruins; as also parts of Motihari, Muzaffarpur, Darbhanga, Kathmandu and Patan, whilst in Sitamarhi, Madhubani and Purnea houses had tilted and sunk in the ground. In Purnea 95% houses rendered inhabitable and 50% destroyed. Along the Ganges, damage in such towns as Patna (220 km SW of the epicenter), Barh (40 km east of Patna and on right bank of Ganges) and Jamalpur (250 km east of Patna and south of Munger) was severe, the roads were choked with bricks and sections of bazars collapsed. Serious damage took place so far as Darjeeling and other places in Bengal.

The earthquake was felt up to distances of the order of 1600 km as far as Peshawar in the northwest, Vijayawada and Ongole in the south, Bombay (Mumbai) in the southwest and Lhasa in the North. The total felt area has been estimated to be about 4.92 million sq km. Loss of life in India was at least 7253 (Table 1) and in Nepal at least 8519 (Table 2) totaling about 16,000. In Nepal many deaths were due to rock falls. Death toll, for such damage was less may be due to time of earthquake being afternoon when most people were outside and the shock reached its greatest intensity in India some two-three minutes after its commencement.

In north Bihar, over a large area roads were badly damaged, railway tracks were completely destroyed, telecommunication dislocated. Railway lines were severely damaged from Raxaul, Sevan, Chhapra in west to Purnea in the east, but lightly damaged along the Ganges track from Patna to Monghyr.

Liquefaction with emission of water and sand was not observed in areas of intensity less than VIII and reached its maximum throughout the slump belt within isoseismals IX and X. Contrary to what is indicated in the Rossi-Forel scale, landslides in Nepal occurred within isoseismals VIII - X, and not solely in isoseismal X. Isoseismal maps as per GSI (Dunn et al. 1939) are shown in Figures 2 and 3. Damage description is from GSI and in some parts of Nepal from Rana (1935, as recompiled by Pandey and Molnar 1988) and supplemented from the account of Nobuji Nasu (Report and photographs, Earthquake Research Institute, Tokyo) who visited the affected areas during May-June 1934. Area wise damage description is given in Tables 1 and 2.

Table 1: Loss of Life in India (Total 7,253)

Place	**Deaths**	**Place**	**Deaths**
Muzaffarpur Town	956	Saran District	193
Muzaffarpur District	1,583	Bhagalpur District	174
Darbhhanga Town	310	Patna District	142
Darbhhanga District	1,839	Gaya District	34
Monghyr Town	1,260	Shahabad District	22
Monghyr District	237	Purnea	2
Champaran District	499	Santhal Pargana	2

Isoseismal X

Intensity X was assigned on Rossi-Forel scale in three areas. Largest area is 140 km SW of the epicentre, a WNW-ESE trending 128 km x 30 km belt in north Bihar from east of Motihari through Sitamarhi to Madhubani and up to Saharsa in the east. The other two areas were small: (i) 200 km south of the epicentre in Munger (Monghyr) around Ganges (ii) 120 km west of the epicentre in Nepal valley southeast of Kathmandu. Munger, Motihari and Madhubani were almost in complete ruins.

Table 2: Loss of Life (total 8,519) and houses destroyed in Nepal

Place	Deaths	No. of Houses			
		Destroyed	Severely Damaged	Fractured	Total
Kathmandu Valley including Patan and Bhaktapur (around 27.25° N 85.1° E)	4296	12,397	25,658	17,684	55,739
Eastern Mountainous Region including Dhankuta, Sindhuli, Udaipur and Ilam (E and NE of Kathmandu, 85.25° E - 86.7° E)	3974	63,947	70,985	-	1,34,932
Western Mountainous Region including Chisapani, Nawakoti, Gurkha, Pokhra (W and NW of Kathmandu at 83.5° E - 85.2° E)	65	795	2,268	1,266	4,329
Terai including Birgunj and Biratnagar (Low lying area near India border)	184	80,893	1,04,521	21,834	2,07,248

Sitamarhi - Madhubani area suffered general subsidence of the ground causing destruction of buildings by tilting and sinking. Many buildings slumped bodily, or individual walls slumped relatively to adjacent walls. Fissuring of the ground was severe and emission of sand reached maximum, covering the floors of houses, streets and drains in towns. Wells were chocked with sand almost to the brim. Fissures were a meter deep. Sand and water vents and crater-like depressions lay in profusion in low lands. Roads subsided. Most masonry bridges either collapsed or severely damaged.

Sitamarhi: In Sitamarhi, a town of 10,000 inhabitants in the Muzaffarpur district, nearly every building came down in the earthquake, no house of whatsoever type escaped tilting or sinking into the ground. This type of damage was best seen in heavy brick buildings. Sand ejection reached maximum intensity here, filling houses, streets, and drains. Large fissures were formed all over the town. Bridges, roads, and railway tracks were either badly damaged or totally destroyed. In places the road sank 2 to 3 m.

Rajnagar (a block headquarter in Madhubani District): Rajnagar was badly damaged by fissures and sand vents, many one-storied houses in this town having suffered from these causes. Nearly all the *kutcha* buildings collapsed, while the majority of the *kutcha-pucca* buildings either came down or subsided. Darbhanga raj palace became ruins. In places, the sand deposits were about a meter high.

Madhubani: About 70 % of the buildings either totally or partially collapsed. The damage done to buildings was aggravated by ground fissures splitting the walls and foundations. The famous temple of Hari Subha, however, stood undamaged. Sand and water vents were common sights in the surrounding localities.

Darbhanga: It is stated that damage here on the whole is less than at Muzaffarpur, the destruction of buildings being not so general, although the heart of the town has been completely ruined. The Darbhanga Raj's buildings and the Nargaona Palace suffered the most. The Post Office buildings, Northbrook School, and Darbhanga Medical School were badly damaged. The earthquake caused the worst havoc at the Katki Bazar, which is densely packed with two-storied kutcha-pucca buildings.

Samastipur: In this town, the maximum destruction was confined to the bazaar area, where a number of two-storied *kutcha-pucca* buildings partially collapsed and others were seriously damaged. On both sides of the railway line, sand was ejected from fissures and the buildings of the sugar factory badly damaged, by shock as well as by ground fissures.

Munger: Munger was a large, flourishing town situated on the right bank of the Ganges and was worst-affected. This town contained an old fort and, in its environs a hot spring called Sitakund, a Hindu pilgrimage. In Chowk Bazar almost all buildings collapsed; the death-toll at this place alone being according to reports (on Jan. 22,1934) about 500. On both sides of the narrow lanes stood a large number of two and three-storied buildings, in which, unfortunately, an unusually large number of people had congregated on this day from the neighboring villages. As Monday, Jan. 15, happened to be "Amabasaya" (Makar Sankranti), the Hindus were looking forward to a bathe in the Ganges, while the Muslims were out shopping in connection with the "Id" festival, so that when the houses began to come down Hindus and Muslims were alike crushed to death.

Munger is built on both alluvium and archaean rocks. As is usual, houses built on hard rock suffered less damage than those built on alluvium. In the fort situated in northwest corner of the city, fort wall collapsed in many places, but the buildings inside it (on archaean rocks) escaped destruction with only slight damage. The main damage to pucca buildings occurred on the alluvium along the edge of the high ground. Ground fissures and slumping happened near the river in the north.

Kathmandu Valley: Kathmandu valley was assigned intensity X or IX. A narrow 30 km long intensity X area 10 km south of Kathmandu runs ENE-WSW from Patan to Bhaktapur (Bhatgaon) through Harsidhi, Khokna and Bagmati. Bhaktapur showed 70% collapse of houses, while at Harsidhi, Khokna and Bagmati there was total destruction. Damage was due to shaking. Temples suffered less, and houses, built of polished bricks generally escaped. Damage in Kathmandu valley and particularly in Bhaktapur was maximum due to 1833 major earthquake, though less than the 1934 earthquake. In 1934, most of the temples at Bhaktapur were destroyed completely or severely damaged. The famous Nyatpola temple, five stories high, was undamaged. The Vhairabh temple collapsed. There was only one small occurrence of liquefaction near Harsidhi.

Isoseismal IX

The areas of very severe intensity IX in Bihar covering 36,200 km^2 (240 kmx150 km), is bounded by irregular elliptical curve. Intensity IX areas are around Isoseismal X in north Bihar, Munger and Kathmandu valley. In Nepal it is possible that there was intensity IX in some areas in the north up to 28° N latitude as described by Rana. Isoseismal IX in Bihar includes a slump belt extending from Betiah in the northwest to Purnea in southeast, a distance of nearly 320 km in which nearly all the buildings were tilted or sank in the soft alluvium. Subsidence of the land was very widespread throughout the slump belt. There were innumerable fissures through which large quantities of sand and water was thrown on the surface due to liquefaction. Severe sand vents were in between longitudes 84°45' to 86°15'E (Seeber et al. 1981).

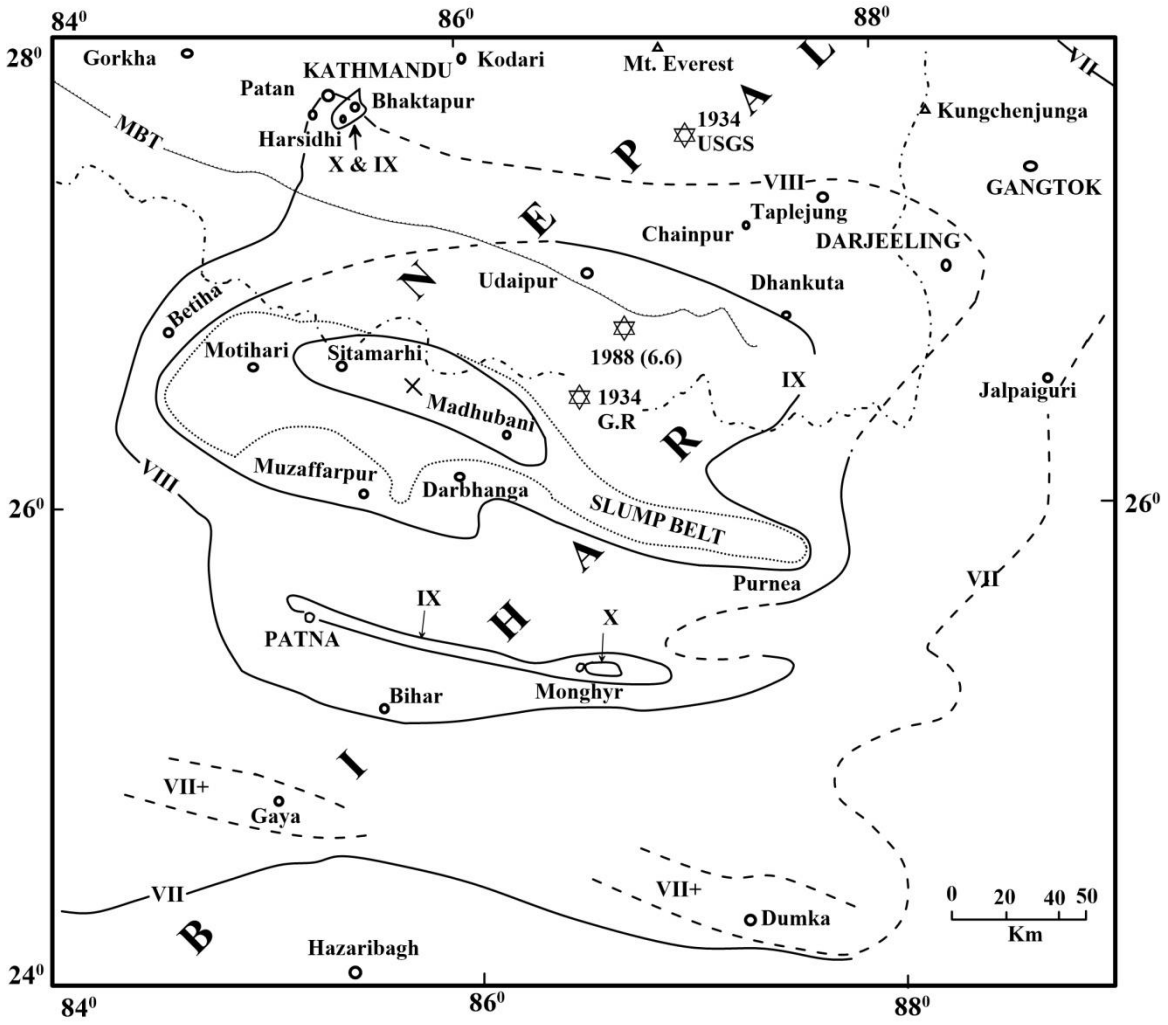


Fig. 2: Isoseismals for 1934 Bihar-Nepal earthquake (after Dunn et al. 1939) and Main Boundary Thrust (MBT). The Main Frontal Thrust is about 30-50 km south of MBT. International boundaries are approximate to give perspective of the area. Boundaries of West Bengal, Sikkim etc are not given. Epicenter of 1934 earthquake given by Chen and Molnar is near USGS location close to Tibet border which is preferred. Epicenter by Seeber et al. is close to that of G-R lying near the Indian border.

In the slump bed of isoesimal IX, the damage was similar to, but less intense than that in isoseismal X. Outside the slump belt in places such as Muzaffarpur and Darbhanga, there was widespread shaking and collapse, but less tilting and subsidence. Fissures in alluvium were near rivers or lakes. Liquefaction was present outside the slump belt also.

Kuchcha-puccca buildings suffered more damage than *pucca* buildings or mud huts. Two or three storied buildings even if well-built masonry structures were damaged, like the Darbhanga palace. Some pockets suffered less damage than intensity IX like two pockets between Muzaffarpur and Sitamarhi.

Nearly all 1400 km railway line in north Bihar was disturbed. Embankments subsided, the track was distorted and every bridge was damaged, many destroyed.

Patna-Munger: A narrow zone along Ganga from Patna to Munger of intensity IX includes towns of Barh and Jamalpur. In Patna, the worst damage took place along the river front. Even fine modern buildings were severely damaged. At Barh also damage was more near to river. At Jamalpur the bazar area and railway quarters near the station were most severely damaged; but newer buildings in the east and south, outskirts of the town were scarcely affected.

Motihari: Here faulting, fissuring, and sand ejection occurred on a very large scale. The principal street of the town had altogether changed in appearance. The picturesque town on the bank of the lake of the same name turned into a sorrowful picture. Owing to subsidence along the margin of the lake, the houses have taken a strong tilt towards the lake. The beds of the Gandak and Burhi Gandak rivers were reported to have risen owing to deposits of sand, while almost all the water channels in the Motihari sub-division have been filled up with sand.

Muzaffarpur: Although the greater part of the town of Muzaffarpur, north of the railway station, suffered very badly, the damage south of the station was less extensive. In the last mentioned part of the town, the buildings were damaged by sinking and cracking of the ground. Most of the one-storied *pucca* buildings, such as the English Church, the Deputy Inspector-general's residence, and the Circuit House, however, withstood the earthquake, while most Government buildings north of the railway station, such as the Civil Court, the collectorate, the Commissioner's court, were badly damaged. Most of the wells at Muzaffarpur were choked up with sand, while the water in the tanks became shallower as their beds were sanded.

Purnea: It is said that the earthquake here lasted fully three minutes. All the large buildings were seriously affected. The Civil Court, the largest building, was seriously damaged by fissures that formed across the foundation, the building subsiding as much as 2 feet. Many private dwellings, particularly two-storied structures, were destroyed; 50 % of the pucca buildings were so badly damaged that they had to be rebuilt. Roads became undulating through local ground sinking, while the wells either dried or silted up. Water spouted out from fissures in many places.

Patna: At Patna, buildings along the river front suffered most. In the bazaar, many buildings collapsed, especially the tall *kutcha-pucca* buildings. The High Court and the Government House showed huge cracks in a number of places.

Kathmandu Valley: The greater part of the low-lying areas in the Kathmandu valley is included in isoseismal IX. The towns of Kathmandu, Patan, Thimi and Thankot were all severely damaged showing 25% collapse of houses. The low-lying areas of the Kathmandu valley have alluvium. The rim areas have pre-Tertiary rocks, granite, gneiss, quartzite and limestone and the houses situated therein escaped severe damage, e.g. in the areas in between Pashupatinath, Bodhanath and Sundarijal. The three temples Pashupatinath, Bodhanath, and Swambhunath escaped severe damage.

Fissuring was rare in Nepal valley and no liquefaction in intensity IX area. The disturbance to the ground was clearly less than in north Bihar and the Nepal Tarai. Damage was mainly due to poor quality construction material.

Isoseismal VIII

Isoseismal VIII encloses areas in Bihar, Bengal and Nepal. In Nepal, areas surveyed by Dunn et al. (1935) were near Kathmandu, Chainpur and Taplejung. In India, the important towns near the isoseismal VIII boundary are Bhagalpur, Bihar, Chhapra, Betiah, Darjeeling and Kurseong; important towns included within this zone were Dhankuta, Khagaria and Samastipur. A number of old and weak buildings collapsed. Brick buildings were somewhat damaged. In newer houses damage was seen in upper stories only. Many mud houses in Begu Sarai were razed to the ground. Destruction was prevalent near the western bank of Gandak river in Saran district.

Fissures and liquefaction occurred sporadically in intensity VIII area north of the Ganges. Railway bridges and roads suffered considerably in this area, but not to the extent as in isoseismals X and IX.

Betiah: The earthquake causalities in this town were not great; not more than at Motihari. Although the surrounding country showed ground cracks and fissures, the town itself showed none. The hospital was ruined and the Catholic Church and Betiah Raj's buildings were all badly damaged. Some 20% of the damaged houses were repairable. The well water was not fouled so badly as at Muzaffarpur and other places.

Isoseismal VII

Dunn et al. prepared isoseismal VII mainly from answers to the questionnaire. Damage in these areas was not obvious at places from outside, e.g. at Gorakhpur. Nevertheless, several large towns situated on the banks of the Ganges, such as, Mirzapur, Benaras and Allahabad evinced a certain amount of major damage of the nature of collapsed houses and severe cracking of walls. There were even one or two sand vents at Benares. A zone of ESE-WNW trending zone of intensity VII+ extended from Dumka to Gaya, further continuing towards Allahabad, Mirzapur and Benares.

Gaya: At Gaya (VII+) the damage was considerable, houses in the localities known as Upperdih and Gayawalbigha suffered the most. The great temple Bishnupada and other famous Hindu temples escaped damage. Many buildings in the town were cracked, while here and there porches came down. In the dry bed of river Falgoo ground fissures appeared at several places from which water and sand gushed out in considerable quantities. The famous temple at Bodh Gaya sustained no damage.

Isoseismal VI

Isoseismal VI includes a number of large towns, such as Agra, Lucknow, Kanpur, Katni, Ranchi, Dhanbad, Asansol, Burdwan, Dhubri, but the most important is Calcutta. This isoseismal extends to the west into Rajasthan for a distance of about 900 km from Sitamarhi. In other directions it is up to about 400 km distance. At Calcutta shaking was felt for minutes. GSI officers rushed out. They noticed considerable movement of lake water. Cracks developed in a number of buildings in Calcutta, but few were serious. Almirah doors were shaken. Fans and hanging lights were swinging for several minutes. At St. Paul's Cathedral, cracks weakened a part of building which had to be reconstructed. An observer on top of a tall building noticed that the building appeared to be describing a meter wide kidney-shaped figure.

Isoseismal V and Lower

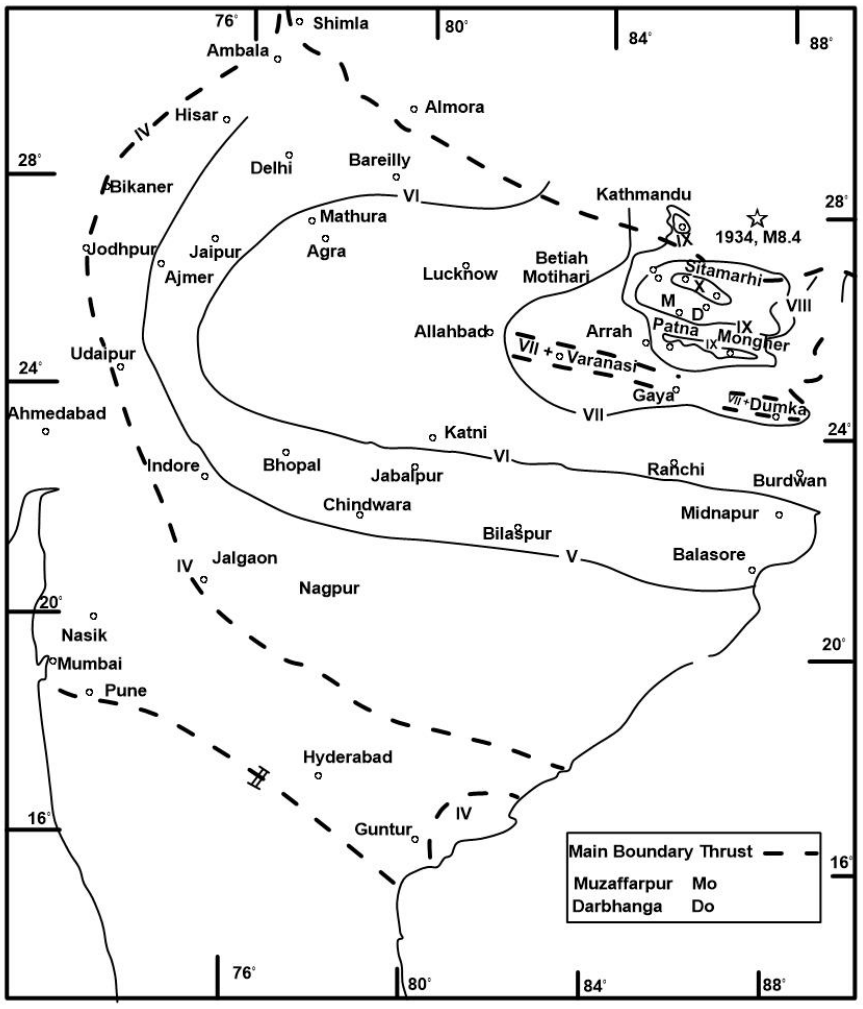
Isoseismal V encompasses towns where some houses got cracks. The towns near the boundary are Ajmer in the west; Chhindwara, Bilaspur, Sambalpur and Balasore in the south; included are Saharanpur, Delhi, Jaipur, Bhopal and Jabalpur. It extends from Sitamarhi to about

1000 km in the west and 600 km in other directions. Isoseismal IV passes through Bikaner, Jodhpur, Udaipur and Jalgaon in the west and Visakhapatnam in the south. However, within this isoseismal the area around Cuttack in Mahanadi delta is included where intensity was V+. Isoseismal III and II are clubbed together and isoseismal II is drawn to show the limit of felt area going through Bombay and Poona in the west and Ongole in south at about 1800 km distance from USGS epicenter. However, the Godavari and Krishna delta area showed intensity IV within isoseismal II.

5. Specific Damage Survey in Nepal

Independent detailed damage survey in Nepal was done by Maj. General Brahma Sumsher J.B. Rana and described in his book in Nepali language published in 1934 and reprinted in 1935. He observed extensive damage in eastern mountainous areas of Lesser Himalaya.

A small area NW of Kathmandu, including Syabru village was severely damaged and assigned intensity VIII, while the **area west and north of the Kathmandu valley** was assigned intensity VII or less. In towns Nawakot (27° 55', 85° 10'), Trisuli (27 56', 85 08') and Betrawati (27° 59', 85° 11') damage was confined to large cracks, except for one village built on an alluvial terrace. Nawakot Bhairabhnath temple was fractured all around and the upper floors were tilted. The northern portion of the Sri Bharaibi temple guest house was destroyed. The Burhi Devi temple was tilted. The uppermost floor of the only 7-storey house collapsed.



Parts of roofs of palaces with the Kalika Devi temple in **Gurkha** (~28.0°,84.5°) collapsed. Around **Pokhra** (~28.2°,84°) the earthquake sounded like a motor. One house in Pokhra was destroyed. In Kaski west of Pokhra there were some landslides. In Bandipur (~27.0°,84.2°), about 70km SSE of Pokhra, 50-60 houses cracked and 10 collapsed.

Fig. 3: Isoseismals of 1934 Bihar-Nepal earthquake for all grades (after Dunn et al 1935). Locations of Betiah and Motihari are within isoseismal IX.

Some 25 km **SW of Kathmandu at Chisapani Gadhi** (district) lying within isoseismal VIII, Batuka temple and several new as well as old buildings collapsed. Houses in several towns of the district were destroyed and there were landslides and cracks on the roads.

Nearly half of the deaths due to the earthquake in Nepal and most of destroyed / severely damaged houses were in the **mountainous area east of Kathmandu** (Table 2)**.** Auden (as described in the report of Dunn et al.)visited southern and eastern parts of Eastern Nepal but not the northern part which was severely damaged. Hence, Dunn et al. have not assigned high intensity to this area. The northern mountainous area (27.25° - 27.50°, 85.5°- 87.0°) was severely damaged. Auden wrote that he was informed that many villages in this area were totally destroyed. Greater devastation in these areas would qualify intensity IX.

Proceeding eastward from Kathmandu, in Chautara district around 85.5° E longitude, especially in the area bordering Tibet, all government buildings were destroyed, including storehouses, barracks, and a powder magazine. Many private houses fractured and some collapsed. **In Kodari**, the millet granary was destroyed and some 7 people died. In Tatopani (5 km SW of Kodari), storehouse for salt was destroyed. All 113 houses of Palchok and all houses of Tauthalikot were destroyed. There were many landslides in the district. **Ramechhap district around longitude 86° E**, suffered similar damage as the Chautara district. In **Rasuwa Gadhi**, some houses were destroyed by landslides and some by shaking. **Okhaldhunga district**, around longitude 86.5 E suffered in the same way as described for Chautara district. Three famous gompas were destroyed, the most famous being in Namche Bazar. **The Bhojpur district** (26.5°-27.5°, 86.5°-87.0°) suffered destruction. Bhojpur market was in total ruins. There was some permanent deformation of the ground as new springs appeared. There were numerous landslides that turned green mountains into white and visibility was lost in dust for 20-25 minutes. Loud sounds were heard coming from north before the mainshock and continued for some days due to aftershocks.

Further east in **Dharan (**about 30 km SSW of Dhankuta) lying within isoseismal IX, Rana noted destruction of a granary, landslides, fissures, new springs and more water in the rivers. He also noted that among government buildings only the powder magazine was less damaged. Auden traversed this area and noted that the damage in Dharan Bazar (26° 49', 87° 17'), "was very severe... and in every house one or more walls had fallen (Dunn et al.), several walls of the Pindeswari temple, and outer walls of Bijapur temple were badly damaged." He noted, however. that : "The houses in Dharan Bazar are badly constructed, having a core of .. boulders..from the rivers, faced on both sides by bricks set in mud binding." **Dhankuta** is at the border of isoseismal IX having relatively less damage than Dharan. Most government buildings and many private houses collapsed, but houses in main part of the bazar suffered some cracks. Some 50 km northwest of Dhankuta and closer to the epicentre, in village of **Chainpur,** Auden described the damage as "very slight". Two houses fell while some others cracked. A few kilometres northeast "at **Nundhaki** (27° 19', 87° 28") there was little damage to village, but numerous landslides were noticed nearby. In **Taplejung,** in eastern Nepal, only the jail was damaged. and some houses in the market area slightly cracked. Thus damage in the NE corner of Nepal was notably less. In the **Ilam district** south of Taplejung, collapse of some government houses and offices and also some private houses was noted.

Coming westward, Auden reported **Udaipur** (26.97°, 86.53°) "almost completely collapsed". Though Auden did not visit villages north of Udaipur, he was informed that many villages were destroyed. **Further NW**, Rana described that at **Sindhuli** (27.28°, 85.96°) all stone

houses were damaged. The governor's house, other government houses and numerous private houses collapsed and some tilted.

The Terai: Rana reported devastation from the eastern border of Nepal to **Chitwan** (longitude 87.6° to 84.5°) in the west in the Terai region close to India border. Both destruction and loss of life was greater in towns than in villages which had bamboo houses with thatched roofs. There were fissures virtually everywhere, sometimes as wide as 4 m and as deep as 30m. Railway was disrupted in the area at many places. Dunn et al. included this area in isoseismal IX. **In Birgunj** (27° 0' N 84° 52'E), large solid houses made of baked bricks and lime mortar were destroyed. Those included govt. houses, the governor's house, and the Muralidarbar. The numerous fissures and the seepage water due to liquefaction was responsible for disruption of railroad and much of the destruction of buildings. The southern parts of the **Mahattari** and **Saptari** districts bordering India at longitudes 85°-86.5° either fall in slump bed (intensity IX or X) or are close to it. In **Mahattari district** (around longitude 86°), Rana reported a wide range of destruction. **In Dhanukha**, pujaris houses collapsed in the temple complex of Ram and Janaki. Some brick houses and the jail were also destroyed. Both Rana and Auden were in agreement that the worst damage in terai occurred in **Saptari district** (longitudes 86°-87°). In Jaleswar (intensity X), Haumannagar and Siraha (both intensity IX) belonging to this district, all solid houses, of baked brick construction, were destroyed and slumped in the ground due to shaking and widespread liquefaction. The governor house, numerous government and private buildings and a granary in **Biratnagar** (26.48° N 87.28° E) were badly cracked, and were rendered useless. Auden also noted that liquefaction occurred as far north as Siwalik hills, but was not common beyond Nipania (26° 48', 86° 21').

6. Conclusion

Great earthquakes in Himalaya, like 1934 earthquake originate at Main Himalayan thrust near the Tibet border, however, rupture area may extend south to Main Frontal thrust. High intensity in India and intensity X areas in India and Nepal due to 1934 earthquake are due to amplification in soft-sedimentary basins, though away from rupture zones. Isoseismals are elongated in E-W direction and more towards west. Destruction due to great earthquakes in Himalaya may extend to few hundred kilometers in Gangetic plains area in India, especially in alluvium covered areas with water saturation which may experience liquefaction and slumping. Due to this reason, destruction area in India extended from USGS epicenter to 200 km in Bihar alluvium basin though the rupture zone of the earthquake was confined within Nepal. Isoseismals of high intensity could not be well-defined in latitude range 27°-28°N in Nepal near the epicenter due to low-population and most damage caused by rock-falls.

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