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SEISMIC HAZARD ESTIMTION FROM THE ISOSEISMALS OF THREE GREAT INDIAN EARTHQUAKES

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SUMMARY

This study is devoted to the construction of anomalous residual intensity maps from isoseismals of three great Indian earthquakes namely, the Kangra earthquake of April 4, 1905 (M_s =8.0), the Bihar–Nepal earthquake of January 15, 1934 (M_s=8.3) and the Assam earthquake of August 15, 1950 (M_s =8.6) for the purpose of delineating areas of anomalous intensities. Computed intensities (I_c) at various localities have been estimated by fitting a simplified model, $I_c = A + B\Delta + C\log\Delta$, into the observed intensity data, where, Δ is the average outer radius for each intensity level and A, B and C are constants estimated using regression analysis. The residual intensities (I_R) are calculated from the difference between the observed intensity (I_{OB}) and the computed intensity (I_c). The anomalous areas of low and high residual intensities have been correlated with geology, tectonics, subsurface topography and Bouguer gravity anomalies.

Four prominent areas of anomalous residual intensities (I_c>2) have been delineated. These areas fall in the Sub Himalaya and the Lesser Himalaya near Dehradun, around Sitamarhi town and Monger-Saharsa ridge in Bihar, and Mikir hills in Assam. These areas are characterized by undulating basement topography and subsurface massif and uplifts in the form of ridges and generally exhibit high Bouguer gravity anomalies. It seems that the basement topography influences the observed anomalous intensities. The expected peak accelerations computed at bed rock level should be modified in these areas of anomalous intensities while making seismic hazard estimation.

INTRODUCTION

The interplate seismicity of the Indian subcontinent is confined to its northern margins and is attributed to the collision of India and Eurasia tectonic plates. For the last more than one hundred years four great earthquakes (M>8) and many large to moderate-sized earthquakes have occurred along the Himalayan plate boundary (Khattri [1]). Estimation of ground shaking hazards due to occurrence of such earthquakes

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is of immense importance for the earthquake resistant design of structures and critical facilities in view of rapid industrialization and growth of urban centers that fall in the seismically active regions along the Himalaya plate boundary covering parts of the Sub Himalaya and the Lesser Himalaya.

Methodology, technical issues and broad perspective related to seismic hazard assessments have been succinctly described by Hays [2]. For the purpose of seismic hazard estimation both acceleration and intensity data are used. The intensity data particularly of large to great earthquakes can be used to estimate the ground shaking hazards in the regions lacking strong motion data. Various types of intensity scales have been devised to measure earthquake intensity (Berlin [3]). The drawback in using the intensity scales is that they combine together the long period and short period effects. The short period effects are roughly correlated with high accelerations whereas the long period effects represent large displacements and are associated with moderate accelerations. Further, with increasing magnitude the proportion of long period to short period effects tend to increase at all distances from the epicenter.

Engineering need is primarily to study the performance of structure subjected to heavy shaking. For this purpose the intensity data and isoseismal maps are of immense value because they reflect the structural damage which is related to earthquake forces and accelerations. It is observed that the earthquake intensity generally shows large variations over a smaller area. If this variation of intensity at adjacent points is mapped in detail then the isoseismal maps can become an index for delineating hazardous areas to be avoided in future construction.

Intensity data, in spite of its qualitative nature, has wide ranging applications in earthquake engineering and engineering seismology. Some of the applications include: studying the attenuation of ground motion (e.g., Khattri [4]), correlation of intensities with accelerations and other parameters like magnitude, epicentral distance (e.g., Murphy [5]), to infer the pattern of faulting from the shape of the isoseismals (Gupta [6]), to give magnitude rating to the historical earthquakes (Nuttli [7]), to correlate the intensities with the ground response characteristics (King [8]) and to study the anomalous residual intensities and their significance in seismic hazard estimation (Algermissen [9]).

In an attempt to correlate the observed intensities with the amplitude and frequency of ground motion, King [8] compared the ground response function in three frequency bands with the observed MM intensities and found that MM intensities within V-VII range appear to be directly related to frequencies within 0.5 to 4 Hz band width. From the wave propagation studies carried out by Kawase [10], it was concluded that the damage pattern of the Whittier Narrows, California earthquake of October 1, 1987 is due to combined effect of topographic irregularities and critically incident SV waves. Algermissen [9] examined the MM intensity data of various earthquakes in the central and eastern United States and found that the ground motion levels in some areas are quiet different from those given by probabilistic hazard analysis. The variation in ground motion due to variation in attenuation or site response may be as important as variation of ground motion generated by different types of seismic source zones. This variation occurs due to the effect of different modelling techniques employed in probabilistic seismic hazard analysis and arise out of uncertainties in both data and knowledge. The present study is devoted to the construction of residual intensity maps from the isoseismal maps of three great Indian earthquakes namely, the Kangra earthquake of April 4, 1905 (M_s=8.0), the Bihar–Nepal earthquake of January 15, 1934 (M_s=8.3), the Assam Earthquake of August 15, 1950 (M_s=8.6), for the purpose of delineating the areas of anomalous intensities. Attempt has also been made to investigate the geological and tectonic significance of the delineated areas of anomalous intensity and their associated seismic hazards.

BRIEF DESCRIPTION OF THE EARTHQUAKES

The earthquake parameters of the three Indian earthquakes are listed in Table 1. The Kangra Earthquake of April 4, 1905 occurred in the Himachal Himalaya, the Bihar-Nepal Earthquake of January 15, 1934 occurred to the south of Main Boundary Thrust in the Indo-Gangetic plains and the Assam earthquake of August 15, 1950 occurred in the Arunachal Himalaya (Figure 1). These earthquakes caused widespread devastation and copious account of the post earthquake investigations are contained in the Memoirs of the Geological Survey of India (Richter [11]). Source parameters of the Bihar-Nepal Earthquake have been studied by Singh [12]. Following is the brief description of the reported damage, shaking and other features associated with these earthquakes.

TABLE – 1 PARAMETERS OF THREE EARTHQUAKE STUDIED (Dasgupta [13])

Name	Date	Origin time Hr:Min:Sec (GMT)	Epicenter Coordinate Lat^{0}N Long^{0}E	Focal Depth (km)	Magnitude (M_s)
Kangra earthquake	April 4, 1905	05:00:00	32.30 76.20	30 to 60	8.0
Bihar-Nepal earthquake	Jan. 15, 1934	08:43:80	26.50 86.50	20	8.3
Assam earthquake	Aug. 15,1950	14:09:30	28.50 96.50	About 50	8.6

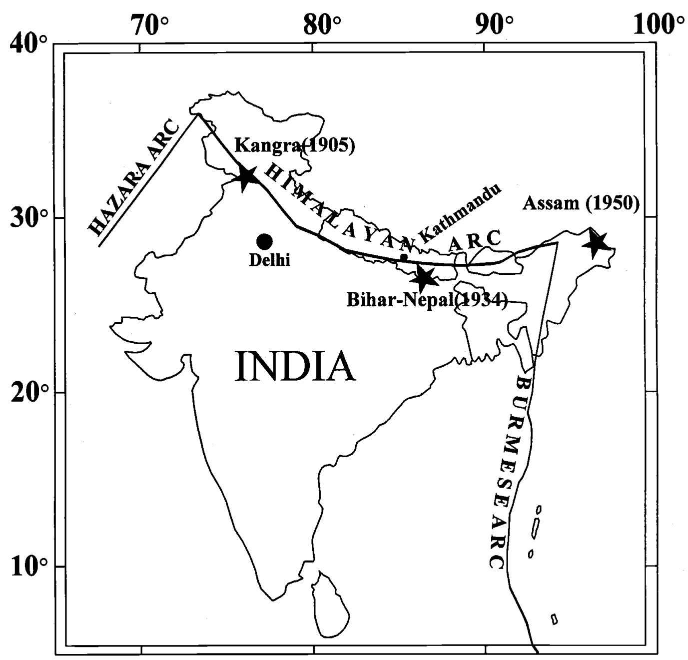

Figure 1 Epicenters of three Indian earthquakes occurred along the Himalayan plate boundary.

The Kangra Earthquake of April 4, 1905

The epicenter of the earthquake was located at $32^0 18'$ N, 76^0 $12'$ E in the Himachal Lesser Himalaya. The main zone of heavy damage to destruction extended over a distance of about 100 km in the south-easterly direction from Kangra to Mandi and a secondary zone of moderate damage was observed near Dehradun (Figure 2). The earthquake took a toll of 19,000 lives and was felt over an area of 41,600 sq km.

Epicentral intensity X was assigned on Rossi-Forrel Scale. Although no fault scarp was visible, from the intensity distribution it was concluded that the earthquake occurred due to displacement along a low angle fault at a depth of 30 to 60 km (Middlemiss [14]). Many villages located to the east, southeast and south of epicenter and falling within a radius of 30 to 50 km from epicenter suffered heavy damage to destruction. Dharamsala township located about 10 km from Kangra suffered heavy damage and almost total destruction at many places. Military and civil staff was reduced to about one-half by deaths. Mclodeganj located at a height of about 6000 feet was leveled to the ground with no building standing even partially (Middlemiss [14]). The meizoseismal area of the earthquake both around Kangra and Dehradun was on the Tertiary rocks of the foothills of the Himalaya and it was most likely that there was a great linear extent of faulting associated with earthquake (Richter [11]).

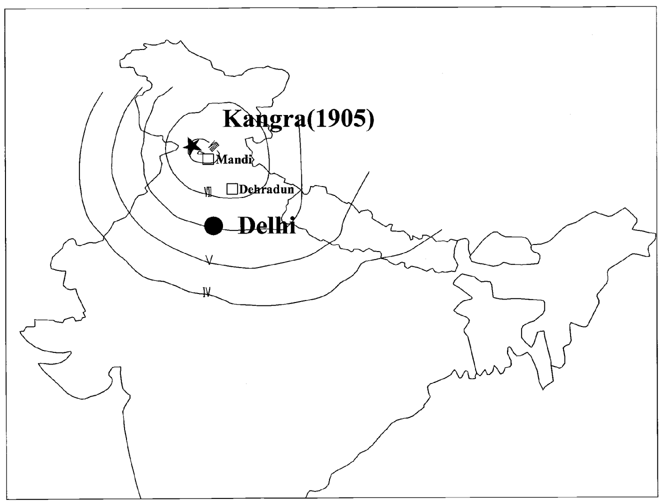

Figure 2 Isoseismal map of the Kangra earthquake of April 4, 1905 (Middlemiss [14]).

The Bihar Nepal Earthquake of January 15, 1934

The earthquake occurred at an estimated depth of 20 km below the alluvium in the Indo-Gangetic plains (Singh [12]). The epicenter was located at $26^0 30'$ N and $86^0 30'$ E and falls to the north of Darbhanga and Muzaffarpur towns and near the eastern end of the slump belt that formed at one end of meizoseismal area suggesting that the rupture propagated towards west (Figure 3). The mean radius of perceptibility of the earthquake was about 1300 km with estimated felt area of about 4.86 million sq km. The earthquake occurred in early afternoon, when most of the people were awake and many were outdoor. In spite of this the reported loss of life was more than 7253 in India and about 3400 in Nepal valley.

Due to extensive liquefaction a slump belt was formed that extended over a distance of about 320 km (Roy [15]). The area covering intensity X was entirely within this belt and almost all buildings and other structures located in the slump belt were titled and slumped bodily into the alluvium. In some cases embankments originally 6 feet high sank down and came in level with the surrounding country. Tanks, lakes, borrow pits and other depressions also became shallower as a result of uplift. Fissuring and emission of sand and water was maximum along this belt (Richter [11]). Less slumping but more shattering was noticed in the areas around Muzaffarpur and Darbhanga being away from focal region.

There were three zones of maximum intensity, the largest being a 128 km long track aligned approximately west-northwest to east-southeast from Motihari to Modhuabani. The second zone of maximum intensity was located at Monger, and the third around the capital town of Kathmandu. The devastation at Monghyr was greater than in any other part of Bihar. To the north of the epicenter there was extensive landslides in the Himalaya (Roy [14]).

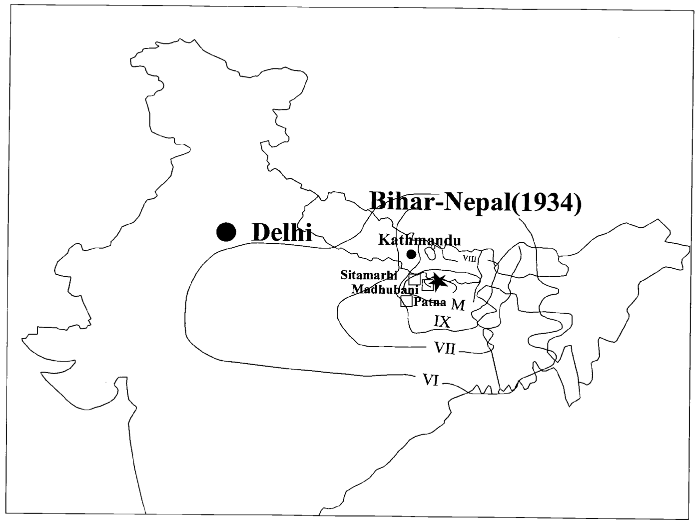

Figure 3 Isoseismal map of the Bihar-Nepal earthquake of January 15, 1934 (Dasgupta [13]).

The Assam Earthquake of August 15, 1950

The epicenter of the earthquake lies near Rima in the Arunachal Himalaya and was located at $28^0\,30^{'}$N and $96^0\,30^{'}$E. The estimated focal depth was about 50 km. It caused wide spread devastation throughout the upper Assam, particularly in frontier tribal districts of Mishmi and Abhor hills, and also parts of Lakhimpur and Sibsagar districts (Tandon [16]). As the effected area was scarcely populated about 1526 deaths were reported. The duration of the intense shaking within the severely affected areas ranged from 4 to 8 minutes. The earthquake was followed by intense aftershock activity and aftershocks were accompanied by a rumbling and booming sound like firing of antiaircraft guns.

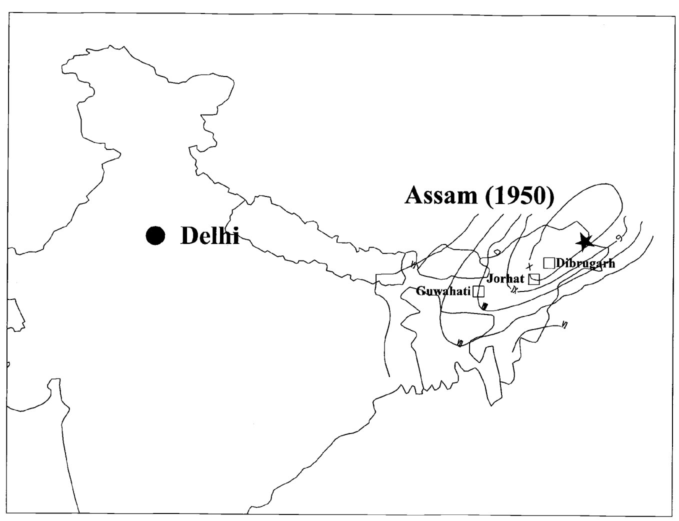

Figure 4 Isoseismal map of the Assam earthquake of August 15, 1950 (Tandon [16]).

Several tributaries of Brahmaputra river particularly Subansiri, Dibang and Tiding were blocked by landslides caused by violent shaking due to the earthquake. The navigable channels of Brahmaputra, particularly those near the hill ranges, underwent considerable changes, partly due to squeezing out and fissuring of soft banks and partly due to silting. The earthquake caused sever damage to roads and bridges. In the urban areas (e.g., Dibrugarh, Jorhat, Tinsukia, Digboi) many buildings were wholly or partially damaged (Tandon [16]).

METHODOLOGY AND COMPUTATION DETAILS

For the purpose of computing the intensity at a particular locality simplified model, $I_C = A + B\Delta + C\log\Delta$, has been adopted (Algermissen [9]). In this model, I_C is the computed intensity, Δ is the average outer radius for each intensity level and A, B, C are constants to be estimated from the intensity data. The residual intensity (I_R) is the difference between the observed intensity (I_{OB}) and I_C. This model is based on point source assumption and isotropic homogeneous medium. It does not incorporate the effect of rupture propagation and amplification of ground motion due to site effect. However, this model does incorporate the uniform attenuation of intensity in all direction from the point source. The observed intensity at a particular site includes the effect of rupture propagation, style of faulting, attenuation and effect of local site geology. The difference in terms of residual intensity between the observed and calculated values shall provide insight into the anomalous behavior of observed intensity that may be attributed to rupture propagation and local site effects.

The isoseismal maps of three earthquakes, as shown in the Figures 2, 3, 4, are used in the study. For the Kangra earthquake the intensities were mapped on the RF scale and same were converted to the MM scale (Richter [11]). This conversion was done because the MM scale is more comprehensive and widely used. Because the RF scale lumps together the higher intensities, the critical examination of the reported damage data was carried out and it was observed that the intensity in the epicentral region that was mapped as X on RF Scale is also X on MM Scale. It is also reported that mapping of higher intensities of VII, VIII, IX and X has been successfully accomplished. However, for the lower intensities VI, V, IV, III and II, the rating was based on the individual questionnaires (Middlemiss [14]).

The area shaken at each intensity level was computed. For those isoseismals that were not closed, some extrapolation was done taking into account the trend of the isoseismals to compute the area shaken. For each earthquake, from the areas enclosed within different isoseismals the equivalent radius in km was computed. Using this data set a regression analysis was performed employing equation, $I_C = A + B\Delta + C\log\Delta$ and the computed values of A, B and C for three earthquakes are given below (Jain [16]).

	Constants		
	A	B	C
Kangra earthquake	14.6361	-7.321985E-004	-1.4932
Bihar-Nepal earthquake	14.4416	2.593 E-002	-2.090
Assam earthquake	30.0463	1.6727 E-003	3.9168

The following regression equations are obtained for the three earthquakes

Kangra earthquake	I_C = 14.6361-7.321985E-004 Δ -1.4932 log Δ
Bihar-Nepal earthquake	I_C = 14.4416 + 2.593E-002 Δ -2.090 log Δ
Assam earthquake	I_C = 30.0463 + 1.6727E-003 Δ -3.9168 log Δ

The isoseismal maps were divided into rectangular grid of 1^0 x 1^0 for the area falling away from the epicenter and to a grid of 0.5^0 x 0.5^0 for area around the epicenter. The smaller grid interval in the epicentral region was taken to map more detailed fluctuations of intensity in the epicentral region. The distance to the each grid point from the epicenter of the earthquake was calculated and used to compute the intensities (I_C) at each grid point using above equations. The observed intensity (I_{OB}) at each grid point was computed by linear interpolation wherever required. For the Kangra earthquake I_C and I_{OB} were computed at nearly 400 grid points, whereas for other two earthquakes these values were calculated for approximately 300 points each.

RESIDUAL INTENSITY MAPS

The residual intensity maps for three earthquakes constructed from the computed values of residual intensity at various grid points are given in Figures 5, 6, and 7. As the intensity is measured in discrete units first the residual intensity contours of -1, 0, 1, 2 were drawn. However, to study further variation in the trend of intensity between these contours, the contours of -0.5, 0.5 and 1.5 were also drawn, under the assumption of linear variation of intensity. Further contouring is not of much relevance because of the large errors and uncertainties involved in mapping of intensities. The intensity observations from which these residual maps have been constructed have at least two sources of uncertainty namely, the uncertainty arising due to interpretation of intensity data by various investigators and the uncertainty resulting from the area adopted to give the intensity rating (Algermiseen [9]). However, these uncertainties are difficult to resolve due to lack of precision in the data. Despite these uncertainties, the estimated residual intensities indicate that some locations show intensity residuals of at least two intensity degrees.

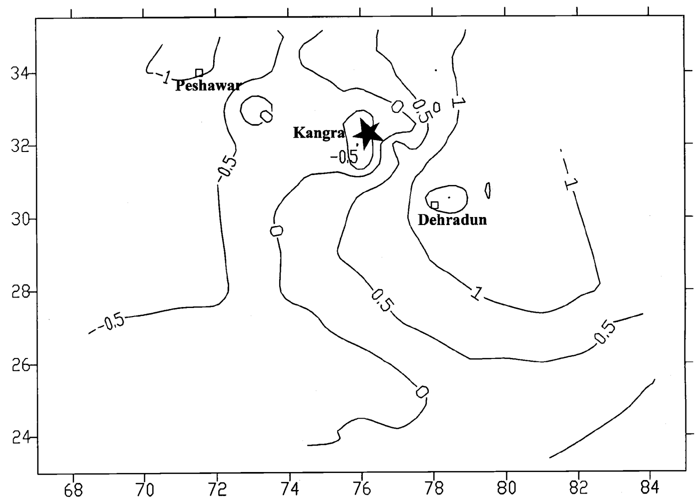

Figure 5 Residual intensity map for the Kangra earthquake.

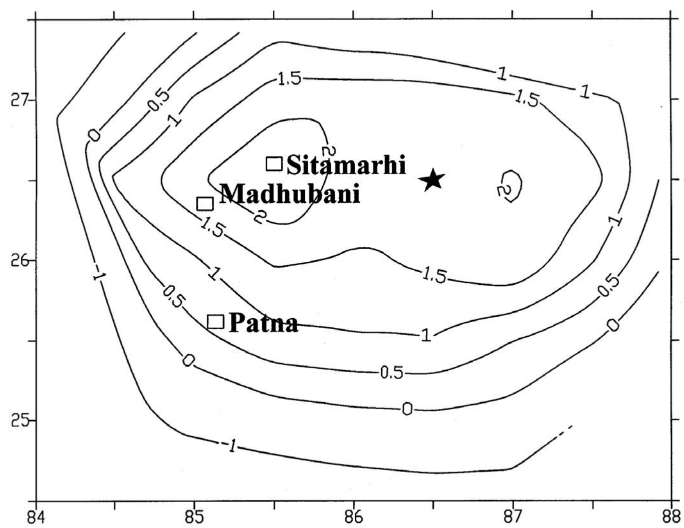

Figure 6 Residual intensity map for the Bihar-Nepal earthquake.

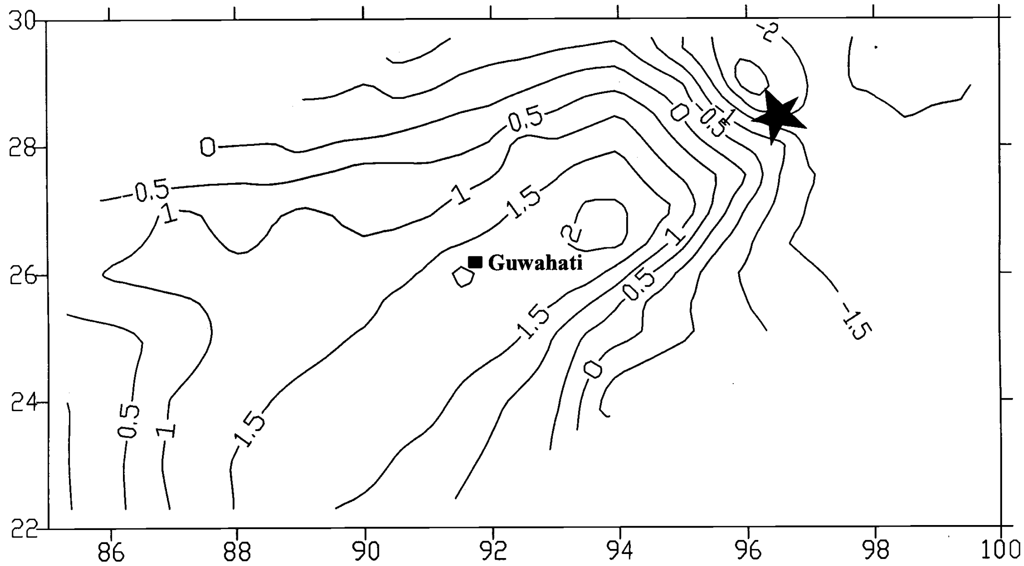

Figure 7 Residual intensity map for the Assam earthquake.

RESULTS AND DISCUSSION

For the purpose of interpreting the significance of the delineated zones of anomalous residual intensities, the available geological, tectonic and gravity data have been employed. As there are no quantitative techniques available to interpret such intensity maps, only qualitative interpretation has been attempted. The significance of such anomalous zones for assessment of seismic hazard is briefly discussed.

The Kangra Earthquake

The residual intensity map for the Kangra earthquake is shown in Figure 5. The residual isoseismals spread from the epicenter both towards north and south. Three areas of anomalous high and low residual intensities have been brought out, namely, i) an area of high residual intensity (I_C=1.5) falling in the Sub Himalaya and Lesser Himalaya near Dehradun, ii) an elongated north-south trending low residual intensity area, falling to the west and in the immediate vicinity of the epicenter, and iii**)** a broad region of low residual intensity located to the west-northwest of the epicenter bounded by latitude 34^0-35^0 and longitudes 70^0-72^0 (Figure 5).

The trend of residual intensities around Kangra and Dehradun areas and geological structure are shown in Figure 8a. The contours particularly of 0, 0.5 and 1 run across the strike of the geological structure and it seems that geological structure does not effect the trend of the residual isoseismals.

The area of anomalous residual intensity brought out to the northwest of Dehradun falls in the Sub Himalaya and the Lesser Himalaya tectonic zones. No apparent correlation of the residual intensities with geological structure could be revealed. However, the area falls to the northeast extension of the Aravalli-Delhi Massif and the Bouguer gravity anomaly ranging between -160 to -280 milligals in the area enclosed by the residual intensity of 1.5 (Figure 8b). It is inferred that the anomalous residual intensity near Dehradun may be attributed to the northward continuation of this ridge like structure namely, Delhi-Haridwar ridge which might be influencing the topography of the basement below the Lesser Himalaya. The area of low residual intensity, located to the west and in the proximity of epicenter, lies partly in the alluvial plains having basement depth of about 4000 mts and partly in the Sub Himalaya and the Lesser Himalaya (Figure 8b). This observed low anomalous intensity seems to be attributed to the defocusing effect because the rupture propagated essentially towards southeast as evidenced by more or less elliptical shape of isoseismals spreading in the that direction.

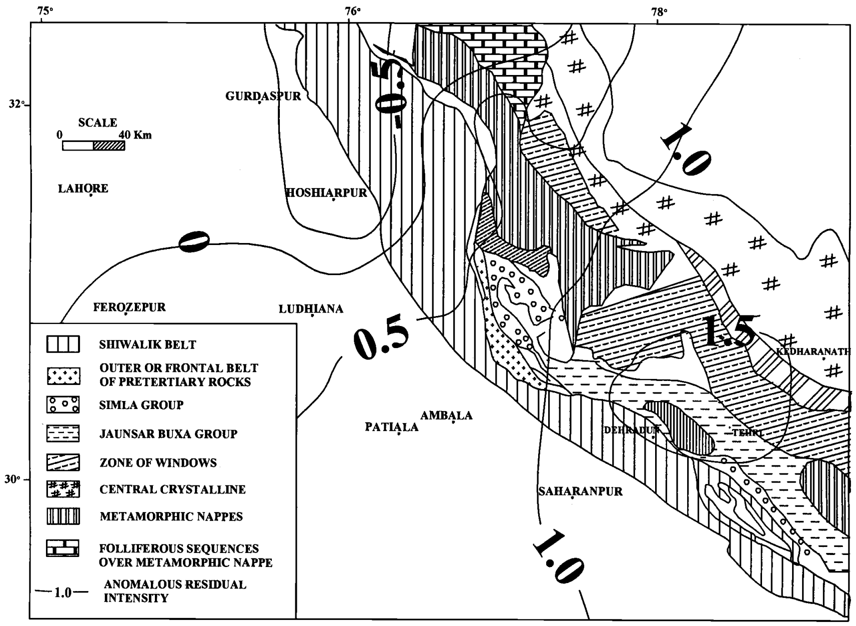

Figure 8a The residual intensities and geological structure around Kangra and Dehradun.

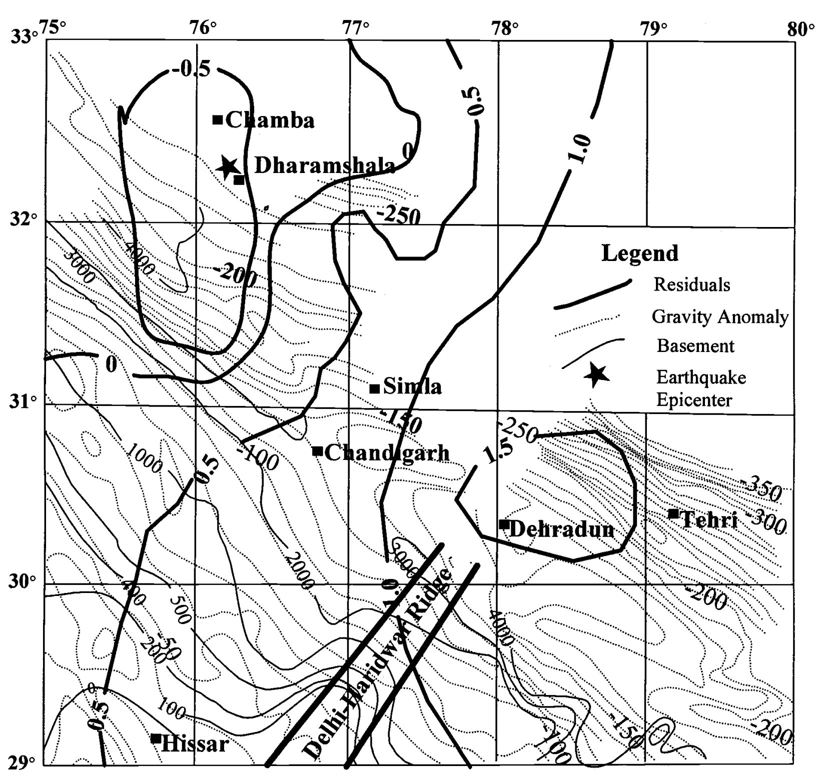

Figure 8b The anomalous residual intensities, Bouguer gravity anomaly and basement topography around Kangra and Dehradun.

The geological formations around area of broad low residual intensity delineated around Peshwar (Pakistan), primarily comprise of lower Tertiary and Mesozoic (Pre-Collision Sediments) and Siwalik and Murree (Post-Collision sediments) (Figure 8c). The region covers post Siwalik basin and is traversed by the Hazara Arc and Bannu reentrant. The formation of reentrant structure is attributed to strike slip faulting at the basement. The Bouguer and isostatic gravity anomalies are also low in this region (Seeber [18]). It is inferred that the area of low residual intensity falls in a basin namely, Peshawar basin and is bound to the west by the strike slip fault namely, Chaman fault.

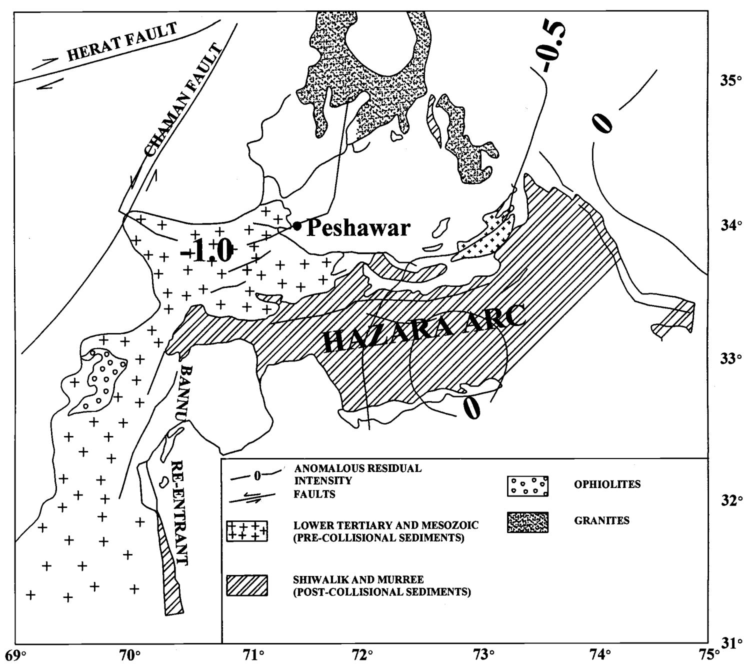

Figure 8c Low residual intensities and geological structure around Peshawar basin.

The Bihar Nepal Earthquake

The residual isoseismal map of the Bihar Nepal earthquake shows two areas of anomalous high residual intensities (Figure 9a). The first area, surrounding Sitamari town in Bihar, indicates residual intensity of +2. This anomalous residual intensity zone is bound to the southwest by west Patna fault and partly coincides with the slump belt formed due to the earthquake. This anomalous area enclosed by residual intensity 2 by and large corroborates with the subsurface uplift mapped on the basement beneath the alluvium in the Indo-Gangetic plain as indicated by the basement topography (Figure 9b). The thickness of alluvium is shallow in this region compared to the surrounding region. To the west in the Ghandhak depression the alluvium thickness is of the order of 6 km (Rao [15]).

The second area of high anomalous intensity lies to the east of epicenter and of much smaller dimension compared to first area. This area falls to the north of Monghyr Saharsa ridge. It seems that the topography of the ridge is influencing the observed residual intensities. A positive correlation has been brought out between the areas of anomalous residual intensities and mapped uplifts on the basement. Further, the isoseismal of 1.0 residual intensity touches the tip of the ridge and almost coincides with the east west trending slump belt (Figure 9a). Bouguer gravity anomalies are also high in the area where the high residual intensity has been obtained (around -150 milligals). Although, the postulated continuation of the Monghyr Saharsa ridge terminates to the south of the observed anomalous intensity zone, the observed gravity anomaly seems to signify that the ridge is continuing below the alluvium.

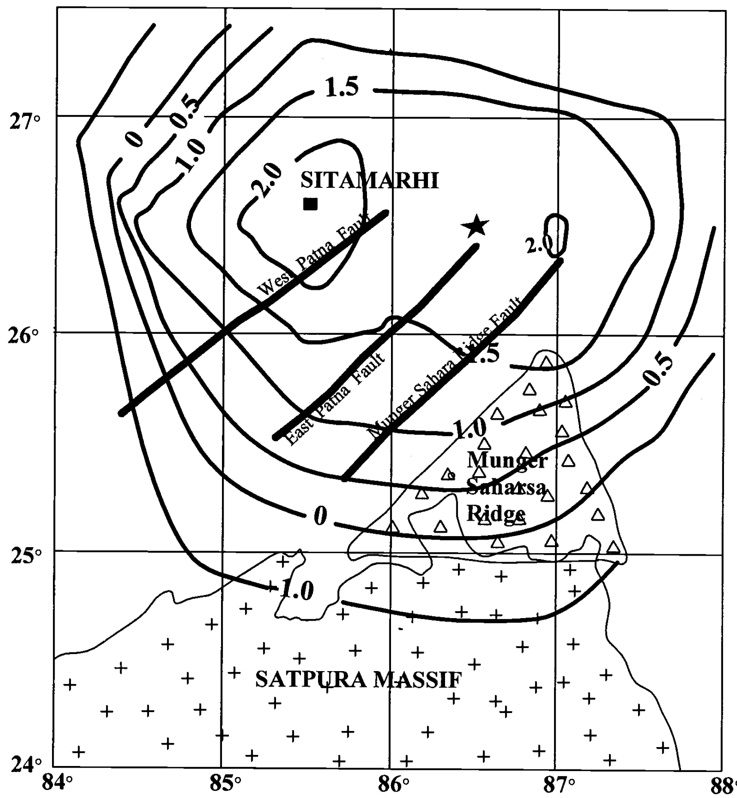

Figure 9a Residual intensities of the Bihar Nepal earthquake along with the geological structures faults and the slum belt.

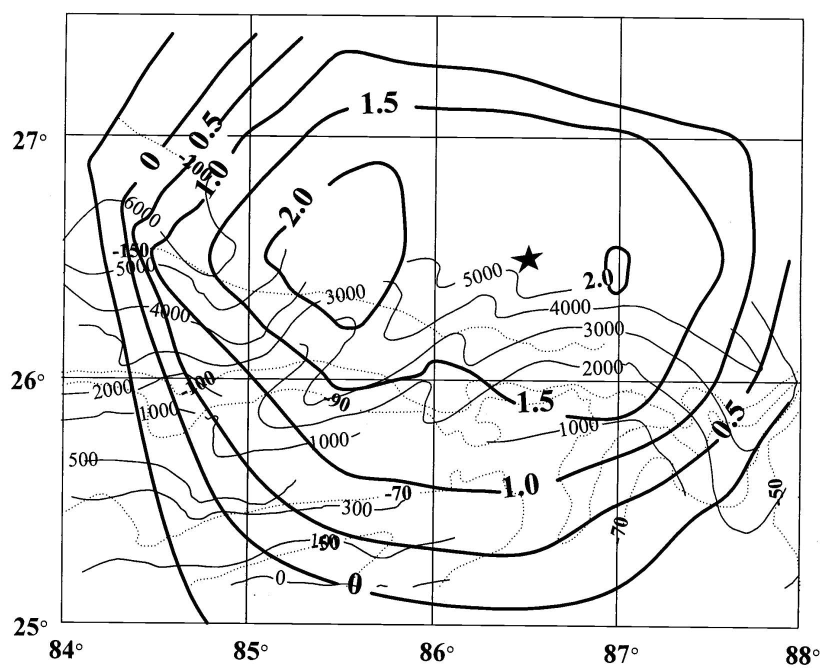

Figure 9b Residual intensities of the Bihar Nepal earthquake along with the Bouguer gravity anomalies and the basement depth (for legend refer figure 8b).

An area of low residual intensities (around -1.0) falls in Satpura Massif which is exposed on the surface (Figure 9a). The variation of residual intensities in the region is attributed to the principal of conservation of energy. The energy is transmitted at a high speed in the ridge that is composed of hard rocks. At the boundary of the ridge and alluvium, due to transfer of energy, the energy propagates at low speed in the alluvium. This result in the building up of amplitudes and associated ground motion and is the cause of the observed high residual intensities in the anomalous areas. Because of the absence of alluvium cover, no amplification of the ground motion occurred in the region which lies on Satpura Massif and thus the observed residual intensity values are low.

The Assam Earthquake

The residual intensity map of Assam earthquake shows two areas of high residual intensity (>2) located about 400 km and 600 km southwest from the epicenter (Figure 10). These areas of high anomalous intensities cover the parts of Mikir hill and the Shillong massif. The larger area of high anomalous intensity above 2 by and large corroborates with the Mikir hill. The Bouguer gravity anomalies in the areas around Shillong massif and Mikir hill varies from -40 to -100 milligals and -100 to -160 milligals respectively (Figure 10). The high gravity anomalies by and large agree with the areas of high anomalous intensities (>2). Generally speaking entire region falling to the south-west of epicenter shows the high residual intensities above 1.

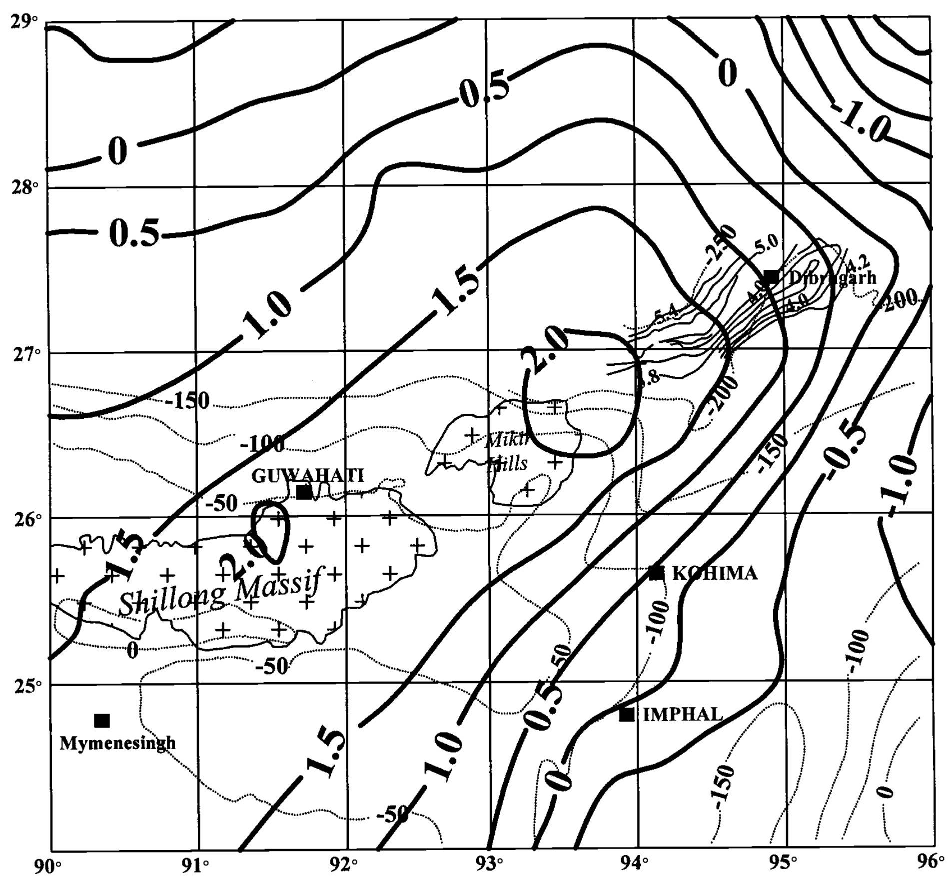

Figure 10 Residual intensities of the Assam earthquake along with the Bouguer gravity anomalies and the basement depth (for legend refer figure 8b).

An area of low residual intensity has been brought out in the proximity of the epicenter. This area, located to the northeast, is ascribed to the rupture propagation effect as from the trend of the isoseismals it seems that rupture has essentially propagated in the south west direction (Figure 7). Areas falling to the south and southeast of epicenter depict low residual intensities. A broad area of low residual intensity located to the south southwest of epicenter falls in the central Burmese basin. The Eocene sediments exposed along western flank of this basin are over 12,000 meter thick. The low intensity residuals seem to be attributed to the large thickness of sediments in the basin.

SIGNIFICANCE OF AREAS OF ANOMALOUS INTENSITIES FOR ESTIMATION OF SEISMIC HAZARDS

The delineated areas of anomalous intensities have considerable significance for estimation of seismic hazards. It is inferred that the expected ground velocities in a 50 year period with a 90% probability almost doubled if the effect of such anomalous zones is taken in to account (Algermissen [9]). Thus, the ground motion associated with sub-regional and local site response is almost of the same order as the ground motion estimated at the bed rock level by employing probabilistic methods incorporating effect of seismic source zones. Khattri [4] computed the expected peak acceleration in rock incorporating the effect of source zones for the exposure time of 50 years. These values are used to draw broad inferences about the effects of anomalous zones on the average value of peak acceleration at bed rock level.

Several empirical relations are available to compute accelerations from intensity data. An empirical relationship $\text{Log } a_H = 0.25\ I_{mm} + 0.25$ based on the statistical analysis of about 900 observations (Murphy [5]) has been used to compute accelerations from intensity. In this relation, a_H and I_{mm} are the peak horizontal acceleration and MM intensity. The anomalous intensity area falling near Dehradun having residual intensity of 1.5 and above, the expected peak acceleration at bed rock level is 0.4g. This approximately corresponds to intensity IX. If the effect of observed residual intensity is included the expected peak acceleration would increase from 0.75 g to 1 g.

In the area around Sitamarhi town the residual intensity upto +2 has been brought out. In this area the peak ground accelerations estimated probabilistically show large variation from 0.2g to 0.6 g. Adopting the above relationship the bed rock intensities fall in the range of VIII to X on MM scale. Incorporating the effect of observed residual intensities the intensities seem to increase from X to XII. This corresponds to acceleration values of 0.56 g to 1.7 g. Same is applicable for the area falling to the north of Monger-Saharsa ridge.

The area of anomalous intensity delineated around Mikir hills in Assam the expected peak acceleration at the bed rock level is approximately ranges from 0.4 to 0.6 g. This corresponds to IX and X intensity on MM scale. Incorporating the effect of residual intensities, the peak accelerations shall increase and fall in the range of 1 g to 1.7 g.

CONCLUSIONS

The residual intensity map of the Kangra earthquake show an area of high residual intensity located near Dehradun. This area falls to the north of Delhi-Hardwar ridge that is mapped below the alluvium and perhaps this ridge like structure lies below this area in the Sub Himalaya and the Lesser Himalaya. The topography of ridge seems to have amplified the ground motion and is the cause of high residual intensities. A broad area of low residual intensity falls in a basin delineated around Pashawar (Pakistan). Two areas of high anomalous residual intensities, falling around Sitamarhi and north of Monghyr Saharsa ridge, have been delineated from the residual isoseismals of Bihar-Nepal earthquake. These areas corroborate with the high topography of the ridge and subsurface Massif. It is inferred that these areas of anomalous intensities are attributed to the subsurface topography of the basement lying below the alluvium. The parts of Shillong massif and Mikir hills also depict high anomalous intensities. The residual intensity more than two by and large corroborates with the Mikir hills. The low anomalous intensities observed in the Central Burmese basin seem to be attributed to large thickness of sediments. The areas of high residual intensities in general show high Bouguer gravity anomalies.

In above four areas of high anomalous intensities, there is an appreciable increase in the expected peak accelerations computed at bed rock level due to the amplification of the ground motion. This should be accounted for while making seismic hazard evaluation for the engineering project sites located in these areas. Other areas namely, the area around Pashawar in Pakistan and the area around Satpura Massif with low residual intensity seem to have low ground shaking hazards.

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