

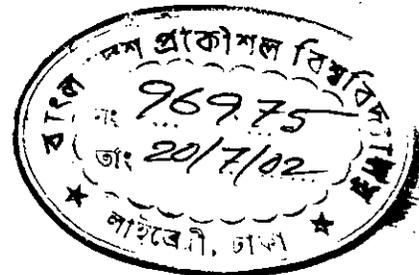
**EARTHQUAKE INTENSITY-ATTENUATION RELATIONSHIP FOR
BANGLADESH AND ITS SURROUNDING REGION**

By

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*A thesis submitted to the department of Civil Engineering,
Bangladesh University of Engineering and Technology, Dhaka
in partial fulfillment of the requirements for the degree*

of



MASTER IN ENGINEERING IN CIVIL ENGINEERING



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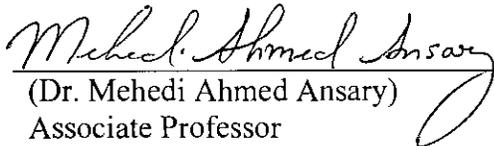
MARCH, 2002

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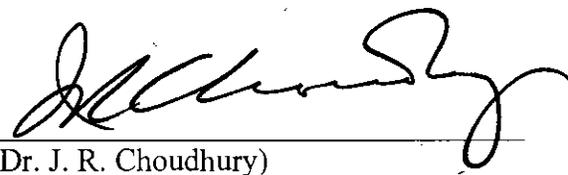
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ABSTRACT

This study presents the results of an investigation of the magnitude-intensity and intensity-attenuation relationships for earthquakes in Bangladesh and its surrounding region using available macroseismic data. When available in sufficient quantity, the macroseismic data allow the determination of very useful parameters such as intensity distribution and its attenuation, macroseismic epicentral location and depth. There is a difference between macroseismic and instrumental seismology. Instrumental seismology deals with what happened during the shaking, whereas the macroseismic seismology is interested in the effects of what happened. The complexity and the multitude of effects produced by destructive events cannot be studied on the theoretical basis only. Thus, the necessity for efficient macroseismic observations to both theoretical and practical needs.

This work is based on a selected sample of isoseismal maps from 18 events. Among these isoseismal maps of 5 events namely 1869 Cachar earthquake, 1885 Bengal earthquake, 1897 Great Indian earthquake, 1918 Srimangal earthquake and 1930 Dhubri earthquake are completely revised here based on European Macroseismic Scale (EMS). Also isoseismal maps of three recent events namely, 1997 Bangladesh-India, 1997 Bangladesh-Myanmar and 1999 Moheshkhali earthquakes are developed for the first time in this study. EMS intensities of the rest of the events are found using existing correlation of different intensity scales. Surface-wave magnitudes (M_s) of these 18 events vary between 4.2 to 8.7. Expression of general form for the magnitude-intensity and intensity-attenuation correlation adopted are as follows:

$$M_{sc} = A_1 + A_2(I_i) + A_3(R_i) + A_4 \log R_i + \sigma P$$

$$I = B_1 + B_2(M_s) + B_3(R) + B_4 \log R + \sigma P$$

where M_{sc} is the predicted macroseismic magnitude, R_i is the hypocentral distance that corresponds to the average epicentral radii $D_i = (R_i^2 - h_o^2)^{1/2}$, in km of isoseismal of intensity I_i and h_o which represents the mean focal depth for the whole data set used, σ is the standard deviation of M_{sc} and the constant P takes a value zero for 50 percent probability that the predicted parameter will exceed the real value and one for 84 percent probability. The data set consists of 18 events with 74 pairs of (I_i , D_i). Three separate analyses are performed using (a) the whole data set, (b) northeast India and Ganges-Basin data set and (c) only northeast India data set.

The results of this study show that the intensity-attenuation models are adequate to predict quite well the die-out of intensity with distance for Bangladesh and its surrounding region; it is also found that magnitude can be predicted accurately by calibrating isoseismal radii against instrumental surface-wave magnitude. Such magnitude-intensity relationships may be used to evaluate the magnitude of historical earthquakes in the region under survey, with no instrumental data, for which isoseismal radii and intensities are available. The intensity-attenuation law developed here can help us to estimate hazard analysis at specified sites.

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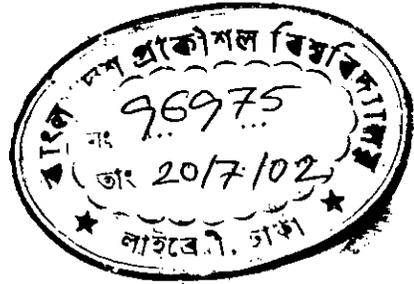
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NOTATIONS

D	epicentral distance in kilometers
I	seismic intensity
h	depth of focus
R	hypocentral distance
M	earthquake magnitude
M_s	surface-wave magnitude
M_b	body-wave magnitude
A & B	regression parameters
σ	standard deviation
P	probability

CHAPTER ONE

INTRODUCTION



1.1 GENERAL

Earthquake is one of the most feared natural disasters which has caused incalculable destruction of properties and human lives. An examination of the historical catalogue of Bangladesh and its surrounding region reveal that several earthquakes of large magnitude with epicenters within this region have occurred in the past. The 1897 Great Indian earthquake with a magnitude of 8.7 (Oldham, 1899) is one of the strongest earthquakes in the world, had its epicenter only 230 km from Dhaka. While the earthquake affected almost whole of Bangladesh, damages were very severe particularly in Sylhet, Rangpur and Mymensingh. In the city of Dhaka most of the brick masonry buildings either collapsed or were severely damaged. The low incidence of severe earthquakes during this century has led to a situation where most of the population and policy makers don't perceive seismic risk to be important. The rapid urbanisation, development of critical engineering works, industrialisation of cities with modern types of buildings and the concentration of populations living or settling in hazardous areas are matters of growing concern, as they contribute to heavier loss of life and increase considerably the costs of disaster damage. In recognition of the threat to the major investment at risk in this part of the world from strong earthquakes, government of the respective countries should multiply and join their efforts to continue the study and analysis of the seismicity of the region with a view to reducing the earthquake risk. The first step in mitigating the risk of the community from earthquake hazard is an assessment of the hazard itself.

Macroseismic earthquake data of the large historical earthquakes are important for seismic hazard analysis. The relationship between magnitude, epicentral distance and intensity of these earthquakes constitute the basic parameter needed for assessing seismic hazard at a given site. The purpose of this study is to present a predicting model for intensity-attenuation for earthquakes in Bangladesh and its neighboring region.

1.2 SCOPE AND OBJECTIVES OF PRESENT RESEARCH

During the last two centuries, Bangladesh and its neighbouring region have experienced several large earthquakes. The intensity of these earthquakes has been estimated using different Intensity scales, namely, Oldham scale and Rossi-Forel scale and Modified Mercalli scale. But for earthquake hazard analysis, a unified intensity scale is required.

The major objectives of the study are as follows:

- (1) Re-estimation of intensity of major historical earthquakes of Bangladesh based on EMS (European Seismological Commission, 1993) scale [description of this scale is provided in Appendix A]
- (2) To develop intensity-attenuation relationship for Bangladesh and its surrounding region.

1.3 OUTLINE OF METHODOLOGY

Intensity continues to be a necessary measure of the size of ground shaking in earthquakes, despite the increase in numbers of strong-motion accelerographs. When evaluated consistently for a large number of earthquakes to represent the seismic activity of a region, macroseismic intensity, as other semiempirical measures, may disclose regular isoseismal models, which can be taken to represent a simple radiation pattern associated with a point source. This approach remains very practical for an efficient evaluation of the interaction between earthquakes and environment and thus for seismic hazard and risk. The attenuation of intensity with epicentral distance constitutes the cornerstone parameter when assessing seismic hazard at a given site. Also, spatial distribution of intensity may be used to assign magnitudes to earthquakes without instrumental data but for which isoseismal radii intensities are known.

Intensity-attenuation and magnitude-intensity relationships are obtained by deriving empirical correlation between intensity, magnitude and epicentral distance for earthquakes for which instrumental magnitude as well as isoseismal maps are available. The magnitude-intensity relationship model procedure used in this study are based on the form expression proposed by Ambraseys (1985). This model is selected because it has been tested for the Balkans, European, Atlas and Turkish earthquakes (Ambraseys, 1985a; 1985b; 1987; Benour, 1993). Kundu (1992) has also used this model for Bangladeshi earthquakes.

1.4 THESIS LAYOUT

The remaining of the thesis consists of three chapters. Chapter two presents the re-estimation procedure and description of five historical earthquakes based on EMS scale. Chapter three deals with the attenuation of intensity with epicentral distance. This chapter also explains the procedure to develop the magnitude-intensity relation for the study region. Chapter four presents the conclusions and recommendations for further study.

CHAPTER TWO

INTENSITY RE-ESTIMATION FOR SOME HISTORICAL EARTHQUAKES

2.1 GENERAL

Field investigation of severe damage caused by earthquakes in the Indian subcontinent has been carried out by the staffs of the geological survey of India from the middle of nineteenth century. The reports on these investigations have been published in the Records and Memoirs of the Geological Survey of India. From the observations of earthquake effects contour lines of different intensities called isoseismal lines have been drawn for different earthquakes using different scales. Oldham (1899) drew the isoseismal map of 1897 Great Indian earthquake using Oldham intensity scale. Later, isoseismal map of 1918 Srimangal earthquake and 1930 Dhubri earthquake has been also drawn using this scale. The isoseismal map of 1934 Bihar-Nepal earthquake has been drawn on the Mercalli scale modified from Rossi-Forel intensity scale.

In this study, to derive the intensity-attenuation model of the study region 18 events are collected. Isoseismal maps of the vents have been drawn based on different intensity scales. Only the isoseismal lines of the recent 3 events are drawn based on EMS scale, which is gaining popularity all over the world due to its better explanation with numerous case studies. In this chapter isoseismal maps of 5 historical events have been reestimated based on EMS scale and their description are also provided. The EMS isoseismal maps of the remaining 10 events have been redrawn using existing correlation between different scales. These correlations are presented in Appendix B.

2.2 1869 CACHAR EARTHQUAKE

The Cachar earthquake of 10th Jan 1869 occurred at 11 h (GMT) is the first and one of the most destructive seismic events that northeast of India and Bangladesh experienced in the last two centuries. According to the seismic history of the region this zone has been the site of high seismic status due to the Dauki fault. The main shock was strong enough to cause the collapse of many local traditional dwellings in Shilchar, Monipur and upper Burma region.

This shock was preceded by a series of foreshock and followed by a series of aftershocks and the earthquake was associated with significant ground surface rupture. Details of casualties and homeless among the population and cost of damage were not known, but it was learnt that there were 5 deaths at Silchar. The earthquake is classified as a heavy destructive event with a focal depth of about 48 km. Compilation and detailed analysis of the macroseismic information inferred from contemporary accounts have led to a re-estimation of intensities. Maximum intensity has been re-evaluated at $I_o = IX$ (EMS) and assigned to Monipur and Shilchar areas. From the intensity data an isoseismal map has been drawn and macroseismic epicentre is located slight east of Silchar i.e. at the northern border of Jaintia Hills at $24.79^{\circ}N$, $93.17^{\circ}E$.

2.2.1 INTRODUCTION

On 10th January 1869 at 17 hr. (local time) this earthquake hit the northeast of Indo-Bangladesh region in the direction of Sylhet and Silchar. It is the first documented earthquake felt in this zone. Silchar town had been shaken to its very centre that serious destruction had ensured. From the damage, it became evident that the district of north Cachar or the hills between that and the Assam must have been the centre of disturbance or near to it. Monipur also had been much shaken and all the country between that and Brahmaputra to the north, an area of about 400,000 sq. km.

The slipping in of the bank of the large rivers or of old riverbeds or partially filled up jheels caused the disturbances in the surfaces. Slips in some cases being continuous for half a mile in length, from 500~1500 feet in width; depth of depression varied from a few feet to 30 feet. Very large quantities of sand and water were thrown up. The most remarkable result of the earthquake was the production of great fissures in the surface of the country and the sinking of the ground over a very large area. Although damage due to this earthquake was widespread, loss of life in such a crowded place was fortunately negligible. The number of casualties reported was five. This was because the earthquake occurred in the afternoon when most of the inhabitants were outside their houses or were sitting close to the door and could therefore easily escape. The earthquake was felt as far east as Burma, west as Patna-Mongyr, north as northern-Assam to Dibrugarh and south as Calcutta-Lakhimpur-Kussilong region. Compilation and critical consideration of the macroseismic data collected from different contemporary documents has led to the re-evaluation of intensities in many sites

and drawing of an isoseismal map. Maximum intensity has been re-estimated at $I_o = IX$ (EMS), allocated to Silchar, Monipur and their surroundings in an area of approximately 50 km radius. From the intensity data the macroseismic epicentre has been relocated slightly east of Silchar at $24.79^{\circ}N$, $93.17^{\circ}E$. Oldham (1882) first published a report containing information regarding this earthquake.

2.2.2 DAMAGE AND CASUALTY

The macroseismic information retrieved from all the sources have been carefully analyzed and then used in the estimation of how the shock was felt and how much damage was caused to man-made structures and to nature in many localities.

In Silchar, all pucca buildings belonging to the PWD were damaged beyond repair besides most of the kutchha building were entirely thrown down. The kutchha bazaar, buildings, boats, merchandise, the sepoy lines and villages were in a complete scene of destruction. The new pucca church tower was fallen and the walls of the jail compound were levelled with ground. The undulating movement was so violent that neither man nor animals could keep their legs straight but were thrown down and bottles glasses lumps were upset. The water in the tank and river was violently agitated and Barak rose in huge waves and wrecked numbers of boats. The landslips were numerous and extensive and many homesteads were carried down into the stream.

Walls of coarse brick masonry with heavy mortar joints enclosed the old cemetery at Silchar, the mortar showed a very wretched power of adhesion. Within the limits of the cemetery there were many monuments of various kinds. The gate of the enclosure was down. There was abundant evidence of a sudden and violent force producing this overthrow. The boundary walls of the cemetery enclosure had been cracked and broken in several places.

Among other buildings, the earthquake caused considerable damage to the deputy commissioner's house: part of the chimney and of the internal dividing walls were shaken down and fell in the rooms. The small hospital attached to the native infantry lines was a perfect ruin. The brickwork was old and of very poor quality; the plain ridge roof was of ordinary heavy thatch in use in the country. All was in ruins.

The high outside wall of the jail had been laid perfectly flat on the ground. A small Hindu temple was uninjured by shelter of a large banyon tree. All masonry structures in the bazaar were in ruins. Trees were seen thrown at every angle; some buried or half buried, the fragmentary ruins of houses and huts one-half standing here the other wildly thrown in a heap there, all in most inextricable confusion. Long cracks or fissures were noticed in every road. Cracks and fissures were seen to be repeated in successive steps down to the water's edge. The total number of lives lost, both in town and district after very careful inquiry were found not to exceed five or six, and very serious injuries to persons were reported.

In Manipur, the earthquake was strongly felt and walking was difficult. Rise and fall of waves were about three feet in height. The upper storey (pucca) built of wood and bamboo settled down with a crash on lower wall, which was much fissured and thrown out. Heavy bookcases and other articles of furniture had been thrown violently. Destruction of crockery bottles was many. The pucca palace was in ruins. It was a two storied brick house, substantial and ornamental building which was only five years old. Here, four women were crushed to death and a number of people wounded. The ground along the banks and near the river was extensively and widely fissured and sunk several feet in many places. Riverbed had been depressed, current was very sluggish. Roads in many places were completely destroyed.

At Morai thana on Burmese frontier, the earthquake was severe. The ground was extensively fissured. Many villages in north were demolished. Hill streams rose by 1 to 2 feet. Earthquake penetrated a considerable distance into upper Burma and was very severe. Northeast of this are was more severely damaged: ground opened into fissures, huts disappeared, and water poured out.

In Pola, 93 km east of Sylhet, the shock was violent enough that an observer was obliged to sit down and hold on ground. About 600 ft west of Pola River and 200 ft south of Barak River, the earth cracked in several places and sank 4 ft deep. Many cracks were observed having width of 3 to 9 inches from which hot water and sand soft and black were thrown out with considerable force and deposited on ground. On the West Bank of Pola the road was four feet height but had sunk level with the main land.

In Sylhet, the steeple of the church was shattered in all direction, two pinnacles fell and two were shifted. Courthouses and circuit bungalow were heavily cracked. Pendulum clocks

stopped vessels of water had their contents thrown out and a large looking glass in circuit house was thrown from the table and broken into pieces. Fissures were seen on the bank of the Surma River.

In Kenomah of Naga hill the earthquake was followed by a great undulation which produced several landslips and fissured the hillsides; the rivers were discoloured and swollen, ground was broken up, and water and sand were ejected from the fissures. The river rose 3 ft two days after the earthquake. The shock was felt in Shillong and Cherrapunji and damage was observed to the public buildings.

In Nowgong earthquake occurred with a rumbling noise. Furniture in the houses was thrown about; the water in the river rose and fell 2 ft to 3 ft; boats were torn from their moorings. The executive Engineer's office was reduced to a heap of ruins. The deputy commissioner's bungalow suffered heavily: walls had fallen down. The hospital and jail (new buildings) completed by PWD was cracked all over. Earth was cracked and fissured in some part of the district. Similar destruction of buildings was seen also in Gauhati. The cows there were much disturbed, flying about and caving wildly immediately before shock.

The earthquake was also felt in Calcutta, where shaking was strong enough to rattle doors and windows and the chandeliers hanging from the ceiling were swinging with considerable force. In Lakhimpur movement was as a vast undulation which seemed to be a great storm. Trees bent and rocked in a fearful manner. It was accompanied by low rumbling noise creating a feeling of nausea. In Dhaka the shock seemed to be from north to south. Some slight cracks in barrack and hospital were found. The shock was severely felt in Dinajpur. Motion was with a rumbling sound like a train in motion.

Damage photographs and sketches of this earthquake are provided in Appendix C.

2.2.3 INTENSITY RE-EVALUATION

Intensities with references to the European macroseismic scale (ESC, 1993) are estimated in this study which is based on available documents. From the analysis of the macroseismic data epicentral intensity is estimated as IX and allocated to Silchar and Manipur areas. The intensity has been assigned to the zone based on the vulnerability of the structures and their

damage grades. Intensities are evaluated at 31 sites and presented in the Table 2.1. As a result of assigning these intensities an isoseismal map of the 1869 Cachar earthquake has been constructed and is presented in Fig 2.1.

Table 2.1 List of sites with estimated intensities based on EMS scale for 1869 Cachar earthquake

INTENSITY	SITE
IX	Monipur, Silchar
VIII	Kochela, Pola, Sylhet, Morai (Burma)
VII	Nowgongh, Kenomah, Shillong
VI	Golaghat, Gauhati, Sibsagar, Jaipur, Dibrugarh, Lakhimpur,
V	Jalpaiguri, Goalpara, Coochbihar, Dhaka, Kusillong
IV	Calcutta, Dinajpore, Darjeeling, Behrampur Barakpor, pabna.
III	Hazaribagh, Purnea, Midnapore, Hugellee, Malda

2.2.4 MAGNITUDE AND DEPTH DETERMINATION

According to Oldham (1882), the length of the fault was 32 km and epicentre was 26°N , $92^{\circ}40'\text{E}$. Based on Oldham's calculation, the average depth of focus is 48 km. According to Tandon and Srivastava (1974), the magnitude of this earthquake is 7.5.

2.2.5 FORESHOCKS AND AFTERSHOCKS

The main shock occurred without any premonitory sign. Although there was no foreshock, but it was followed by a series of aftershocks until February 25, 1869, with one aftershock of magnitude comparable to the main shock. Five shocks were felt on January 10 (the first shock was reported as severe), one shock each on January 11 to 13 (the shock of the 12th was reported as severe), two shocks on January 18 and February 21 were felt by several observers.

2.2.6 DISCUSSION

The 10th January 1869 Cachar earthquake was one of the oldest recorded seismic events in Indo-Bangladesh region. Prior to this a minor earthquake shook Silchar in 1866. The study of this earthquake is of great importance for the region for a number of reasons. First it is the first well-documented large earthquake of this particular region. Secondly the same epicentral zone and its surroundings has experienced several devastated earthquakes in the last century due to the presence of Dauki and other fault systems. Due to this a detailed study and analysis of the effect of this earthquake on the region is relevant to the whole of the northeast of Indo-Bangladesh region in terms of seismic hazard and risk evaluations. It contributes substantially to the reduction of seismic risk by suggesting new ways of improving local construction procedures, building material characteristics, strengthening and repairing of existing structures as well as layout and implementation of new urban and rural sites.

However, for a better understanding of information contained in contemporary documents, the accounts were considered in context of the period concerned; that is the political, socio-economic and demographic conditions, cultural and religious background and characteristics of the building stocks exposed to the shaking. The earthquake occurred in the middle of the British colonization period, Lushai disturbances at that period interrupted collecting statistics from Monipur, which was severely damaged.

Summarizing the result, following data has been obtained. Origin time 11h 3m (GMT); Macro seismic epicenter at 93.17° E, 24.79° N; Maximum intensity $I_o = IX$ (EMS); Depth of focus = 48 km; Magnitude = 7.5.

2.3 1885 BENGAL EARTHQUAKE

The Bengal earthquake of 14 July 1885 occurred at 12h 22m (GMT). The main shock was strong enough to destroy numerous houses and important public buildings. Poor quality constructions were one of the main causes of damage. The shaking was strongly felt in the whole area encompassing Rangpur, Bogra, Sherpur (Mymensing), Mymensing, Dhaka, Pabna where destruction to building was the greatest and loss of life had occurred. The main shock

was followed by a series of aftershocks and the earthquake was associated with significant ground rupture. After considerable analysis of the macroseismic information retrieved from the sources available, maximum intensity is re-estimated at $I_o = \text{VIII-IX}$ (EMS) and covers Serajganj, Sherpur (Bogra) and their close vicinities an area about 50 km radius. The earthquake is classified as a heavy damaging one with a focal depth of 72 km. The macroseismic epicenter was located slightly southeast of Serajganj at 24.7° N, 89.55° E and an isoseismal map of the main shock has been constructed. According to Bolt (1987), the surface wave magnitude of this earthquake is 7.0.

2.3.1 INTRODUCTION

The Bengal earthquake of 14th July 1885 was felt violently throughout Bangladesh. It extended westwards into Chota Nagpur and Bihar, northwards into Sikhim and Bhutan and eastwards into Assam, Monipur and Burma. The area over which it was sensibly felt may be roughly laid down as 600,000 square km. An irregular ellipse drawn through Daltangunge, Durbhanga (Bihar), Darjeeling, Sibsagar, Manipur and Chittagong will give the external boundary of that area. Within this, again, another irregular figure may be drawn through Calcutta, Sitarampur, Mongyr, Purnia, Siliguri, the Garo hills, Chatack and Barisal, which will enclose an area over which the shock was felt with much considerable violence as to shake loose objects, rattle windows and produce small cracks in double-storied houses. There was another area bounded by Rangpur, Bogra, Sherpur, Mymensing, Dhaka, Pabna where destruction to building was greatest and loss of life had occurred. The earthquake occurred without any premonitory sign but was followed by a series of aftershocks. Compilation and detailed study of the contemporary source documents relative to this earthquake have led to the re-assessment of the strength of the ground shaking. Intensities were re-evaluated in many sites. Maximum intensity has been re-estimated at $I_o = \text{VIII-IX}$ (EMS) and allocated to Serajganj, Sherpur and Jamalpur and their close surroundings an area about 7500 square km. From the intensity data an isoseismal map has been drawn and a macroseismic epicenter located slightly north of Serajganj at 24.7° N, 89.55° E. The earthquake was recorded in two seismological stations. The surface wave magnitude was recorded without station correction, at 7.0 by Bolt (1987). Middlemiss (1885) first published a report containing information regarding this earthquake.

2.3.2 GEOGRAPHICAL ASPECTS OF THE REGION

The native house and the European houses in Bengal are both built on two entirely distinct plans and with entirely different materials. One style of house is single storied erected by driving roughly shaped tree trunks or wooden posts into the ground, filling into the interspaces with split-bamboo mats, and throwing a highly-pitched thatch roof on to bamboo rafters; the whole of the latter being held in position by means of ropes and thongs attached to the main posts. These bamboo grass houses are well calculated to stand the stresses due to an earthquake shock on account of the ready pliability. The other kind of house, though differing architecturally according as it is of native or European design, agrees in having brick walls, frequently raised to two and sometimes to three story covered with plaster or stucco and usually bearing a heavy solid flat roof of brick and cement surrounded by parapet. These houses have all been badly rent sometimes beyond repair or even ruined. There is occasionally a kind of house which partakes of both the above described styles, having brick walls and a thatch roof and there are in addition many huts of dry mud and thatch belonging to the poorer natives. Both these kinds have suffered very much for the former whilst possessing all the defects of unpliable walls, has none of the advantages of a strong flat roof to tie them together and the latter of course readily cracks and crumbles on account of its material lacking coherency.

2.3.3 DAMAGE AND CASUALTY DISTRIBUTIONS

Detailed study of the macroseismic information retrieved has considerably contributed in the re-evaluation of the amount of damage experienced by man-made structures and by the ground itself. The earthquake caused heavy damage to the constructions in the area around Serajganj and Mymensingh. The earthquake broke two chimneys (height 135 and 95 feet) of Jute works in Serajganj. The chimneys broke down around 40 feet and 11 feet from the summit respectively. According to the eyewitnesses, the upper part of the chimneys were first shattered and jerked off by a sudden thrust below; and for sometime a shower of bricks and mortar continued to fall all-round the base. The shock was nearly diagonal with regard to the four main walls of the building (rectangular). Due to the presence of iron-tie rods that are used throughout to bind the walls together comparatively little damage has been done to the wall. Cracks are formed near its junction with the roof. Another house at Serajganj a double storied—the upper part has been the most damaged; it was the largest house in Serajganj and

had been the most decisively cracked. Joint magistrate's house, single storied house with brick and plaster walls but with a thatch roof, had suffered severely. Another single storied house with flat solid roof and solid walls showed cracks on the roof. Several native houses were also shattered and one of them shocked away by a plane of fissuring.

In Sherpur (Bogra district) there were small Hindu shrines of god Shiva, octagonal in shape, the height being usually two or three times the diameter. In every way they were good subjects for observing the direction of the cracks, for their solidity and symmetry prevented the fissures from being influenced by any pre-disposing lines of weakness: a couple of cracks in these temples were reported. They were exceedingly well cut fissures and discernible at a good distance. Besides the temples, there were many examples of house corners shot away, generally in northwest direction. Around 100 houses were completely destroyed in this town.

In a small cemetery at Jamalpur a tomb had fallen, which was erected in 1837. The tomb was surrounded by eight pillars in a circle and covered by a hemispheroidal dome or canopy. This was built of brick and stucco. All pillars had fallen in one direction and split up into various lengths; whilst the great heavy canopy had fallen towards the south 10° east.

In Mymensingh, a Hindu shrine of Shiva, octagonal in form and with a conical apex, a distinct crack was discovered at the lower story. A heavy brass water-vessel threaded on an iron rod, forms an ornament for the summit of the conical roof was bent over towards the southeast at an angle of about 60° with the horizontal. One of the enclosure wall of the district jail was cracked for a long distance near the bottom; another wall was parted from it outward, leaving a gap of an inch or so wide. Walls of a dispensary showed a set of intricate fissures, crossing one another at right angles and such as could have been produced by a fissuring plane dipping at 45° . A mosque near the dispensary was found with its corner walls shot away. There was also a horizontal crack in one of its wall at about half its height. The local palace received the full effect of shock as its end walls completely fell down. A new kachari was affected by few small cracks and falling of cornices at several points.

At Subornkholi and Muktagacha some houses were cracked and a small chimney stalk rent near the summit. Also in Muktagacha, a gateway was overthrown, which was faced south- 13° -east and the arch had been cut clean off on a level with the top of the gate-spikes.

Earth fissures opened at Serajganj, Subornkholi and Jamalpur and few other places; they had taken place either by the banks of a river or elevated roadway or the sloping sides of a pond. In Subornkholi there were some irregular cracks opened on a flat. They were fringed all round the margin by fine sand; water oozed up through these cracks carrying the sand with it and sometimes even spurted up into the air some few feet. At Jamalpur some pieces of lignite had been similarly thrown up through fissures along with sand and water. Wellpipe (1.5 inch diameter and 13.5 inch long) in Serajganj was filled throughout with sand. A well had its tiled casing (1.5 feet diameter) displaced at Subornkholi. Some brickstacks in a brickyard in Mymensing were overthrown.

Dhaka got very little evidence of the earthquake, though the shaking was severe. A temple had fallen at Barisur on the opposite side of the river. It was an old building. Several other houses had cracks in the wall and cornices and plaster falling.

Damage photographs and sketches of this earthquake are provided in Appendix C.

2.3.4 INTENSITY RE-EVALUATION

Intensities with reference to EMS scale have been reestimated in this study using macroseismic data collected from contemporary documents. As a consequence of the high vulnerability of the construction of the region, the maximum intensity in destructive earthquake appears to be the same. That is at intensity XI on the EMS scale all traditional houses are totally destroyed and any village would thus look equally but no more devastated at higher intensities of the scale. From the analysis of the macroseismic data, maximum intensity was re-estimated as $I_0=VIII$ (EMS) and allocated to Serajganj, Sherpur (Bogra) and Jamalpur. The intensity has been assigned to the zone associated with maximum damage to structures and to nature. The intensities have been re-evaluated at 27 sites and are presented in Table 2.2. As a result of the analysis of the macroseismic data available, a new isoseismal map of the great earthquake of 14th July 1885 has been constructed and is presented in Fig. 2.2.

Table 2.2 List of sites with re-estimated intensities based on EMS scale for 1885 Bengal earthquake

INTENSITY	SITE
VIII	Serajganj, Sherpur (Bogra), Jamalpur, Muktagacha, Mymensing, Bogra,
VII	Dhaka, Sherpur (Mymensing), Subornkholi, Pabna, Rangpur, Natore
V	Calcutta, Sitarampur, Monghir, Purneah, Siliguri, the Garo hills, Chatak, Barisal.
III	Daltangunge (Palamow), Durbhanga, Bihar, Darjeeling, Sibsagar, Manipur, Chittagong.

2.3.5 MAGNITUDE AND DEPTH DETERMINATION

According to Middlemiss (1885), the epicentre of this earthquake was at 90.11°N , 23.99°E and the average depth of focus was 72 km. According to Bolt (1987), the magnitude of this earthquake was 7.0 in surface-wave magnitude scale.

2.3.6 FORESHOCK AND AFTERSHOCKS

There seems to be no doubt that the forerunner of the destroying earthquake of the 14th July is to be found in the gentler, but still violent shock which was felt in Calcutta and Darjeeling in June 25. It is certain that the later smaller shocks and tremors have proceeded from about the same center as that of the main shock. These later ones happened on the following dates and though doing no damage, they kept the population in a constant state of expectant alarm. A single shock was felt on July 21, two shocks on July 22, three each on July 23 and 26, and one each on August 4 and September 5.

2.3.7 DISCUSSION

The 14th July 1885 earthquake is the first felt and recorded destructive seismic event in Bangladesh. The re-construction of the macroseismic field of this event is of great importance for many reasons. As it represents the first felt and recorded earthquake in Bangladesh. Also the same epicentral zone and its surrounding is very close to the 4.8 km long Jamuna

Multipurpose bridge connecting northwestern part of Bangladesh with the rest of the country. For this purpose Prof. Bruce Bolt of University of Berkeley, California, USA studied this earthquake in detail during the feasibility stage of this bridge in 1987.

Summarizing the result, following data has been obtained. Origin time 12h 22m (GMT); Macroseismic epicenter at 89.55° E, 24.7° N; Maximum intensity $I_o =$ VIII to IX (EMS); Depth of focus = 72 km; Magnitude = 7.0.

2.4 1897 GREAT INDIAN EARTHQUAKE

The great earthquake of 12th June 1897 occurred at 11 h 15 m (GMT), is the largest destructive earthquake in Indo-Bangladesh region since the beginning of the past two centuries. The main shock which lasted 120 s in Shillong and Tura caused the loss of more than 1600 lives, made many homeless and collapsed numerous houses, private as well as government buildings. The shock was strongly felt in the whole area encompassing Calcutta, Bihar, Patna, Bhagalpur, Agartala, and Faridpur where it caused panic among the population. The radius of perceptibility was about 1000~1200 km away. The main shock was followed by a series of aftershocks and the earthquake was associated with significantly large fissures, landslides and liquefaction. In order to reconstruct the macroseismic field of this earthquake, a broad investigation of contemporary documentary materials relative to this event was carried out. The result of this search has led to a re-evaluation of the extent of damage to both man made structures and nature and to an appreciation of the behavior of the population. After considerable analysis of the information retrieved from the sources available, maximum intensity is re-estimated at X in the EMS scale and covers Tura, West of Shillong and their close surroundings. The earthquake is classified as a devastating one. The main shock was recorded by Milne seismograph. The surface wave magnitude was computed without station corrections at 8.7 (Gutenberg and Richter, 1954). In a recently published paper Ambraseys (2000) modified this value to 7.98. From the intensity data an isoseismal map has been drawn and a macroseismic epicenter has been located near at 25.84° N and 90.38° E.

2.4.1. INTRODUCTION

On 12th June 1897 at 5 h 15 m (local time) a destructive earthquake hit the region of western portion of Assam which for violence and extent has not been surpassed by any other earthquake. The most affected area lies on Tura and Shillong the capital of Garo and Khashi hill district respectively. According to the seismic history it is reported as an exceptional earthquake. The main shock lasted about 120 seconds and its damage to stone and brick building was universal. An area of 385,000 sq. km. had been laid in ruins, all means of communications were interrupted, the hills rent and cast down in landslips, and the plains fissured. Sand and water poured out from numerous vents. Total felt area was 45,00,000 sq. km.

The compilation and critical consideration of macroseismic data collected from different contemporary documents has led to the re-evaluation of intensities in many sites and drawing of isoseismal map. The earthquake occurred without any premonitory sign but was followed by hundreds of aftershocks with two aftershocks of magnitude comparable to the main shock. The shaking was felt as far west as Allahabad, north as Lhasa of Tibet, east as Hukong valley Burma with intensity VII, VI and VI respectively. Maximum intensity reached X (EMS) in Tura and its close surroundings. From these intensity data an isoseismal map of the earthquake has been drawn and the macroseismic epicenter has been relocated at 25.84^oN, 90.38^oE. Detailed report containing information of this earthquake was published by Oldham (1899).

2.4.2. GEOGRAPHICAL ASPECTS OF THE REGION

The epicentral area lies on the western flank of Assam. This part contains mountainous zone at which the height is around 4000 ft. above mean sea level. The effected zone was remote and sparsely inhabited. The main range of Tura hill and it's conformity of spur consists of a backbone of sandstone covered with more or less deeply with a loose reddish sandy soil, plentifully mixed with boulders gneisses. The crests of the spurs are broad and fairly level but the sides are steeping occasionally precipitous. At the bottom of each ravine is a small stream flowing over rocky bed.

Four types of houses were observed. First type buildings were built on wooden piles driven several feet into the ground and reaching up to the roof. These have a raised board floor, mud and reed walls supported by timber battens and a roof of thatch or corrugated iron. Second type of houses has stone and cement plinth instead of raised board floor. In this class are civil surgeon house, charitable dispensary, post office, treasury and some shops. Third type has ground for the floor, timber or bamboo frames with walls of mats or reeds lightly plastered over and roofs of thatch or corrugated iron. Fourth class consists of Garo houses with a raised floor and built entirely of wood, bamboo, cane and thatch.

2.4.3 DAMAGE AND CASUALTY DISTRIBUTIONS

Detailed study of the macroseismic information retrieved has considerably contributed in the re-evaluation of the amount of damage experienced by man-made structures and by the ground itself. The earthquake caused total destruction and heavy damage to the Garo and Khasi hill districts particularly to Tura and west of Shillong. On either side of the Garo and Khasi hill districts landslides are everywhere conspicuous in sandstone country and larger and more abundant on the southern face of Tura. Cracks and fissures are seen everywhere in the vicinity of landslips and the upper edges of sloping ground. In the plain portions of the district (Garo), deep cracks and crater-like pits appeared in the ground. One of the pits is as much as a mile long, 2~3 feet wide and 16 feet deep. The pit is 6 feet in diameter. Through these fissures jets of water and sand were thrown up to a height of 6~7 feet, in a few cases accompanied pieces of coal peat resin masses of semipetrified timber. Many houses sank into the ground bodily, the roof alone being visible but no loss of life has been reported. Several villages were and still are partly submerged and some thousand bighas of cultivable land have been made useless. The earthquake caused a regular panic amongst the plains. Whole villages were destroyed, while the inhabitants took refuge in the hills. Some hills have sunk bodily many feet while others have risen. More losses of lives has occurred in Someswari valley of Tura. For days after the earthquake the Someswari river was choked with thousands of dead fish floating down from the upper reaches. Two dolphins were found dead by the shock.

At Shillong, a deep rumbling sound like thunder, commenced, coming from the South or SouthWest, followed immediately by shock. The ground began to rock violently and in a few seconds it was impossible to stand upright and people had to sit down suddenly on the road.

The surface of the ground vibrated visibly in every direction as if it was made of soft jelly and a long crack appeared at once along the road. The school building began to shake at the first shock and large slab of plaster fell from the wall at once. A few moments afterward the whole building was lying flat, the walls collapsed and the corrugated iron roof lying bent and broken on the ground. According to an observer, the motion was so violent that it was unable for him to stand but crawl on his hands and knees and hold on to a tree for support. Several stone structures the church telegraph office, superintendents and subdivisional officer's offices simply collapsed owing to the stones being shaken out of their position. The roof in all these cases has simply fallen almost exactly over the place where the supporting walls were.

At Goalpara, assistant Commissioners bungalow situated on the crest of ridge near river has entirely fallen. Treasury-a massive brick building standing at foot of the hill has fallen and destroyed. In bazaar, large fissure opened under the house along one side. From it a large quantity of sand was ejected filling interior of the houses up to the eaves. Surface of the ground subsided, carrying houses with and roofs resting on the sand. A wall entirely filled with sand and ejection of sand had such a force that covers of wells (wooden) was hurled 30 feet where it lies half buried. Telegraph office destroyed entirely and municipal boundary pillars overthrown.

In Coochbehar, most brick buildings have been severely damaged. Superintendents house broken into two by fissures under it. Palace turrets fell and particles overthrown. Between Coochbehar and Alipur dour road is fissured and bridges broken. All stone buildings were damaged, many collapsed completely. Hill sides are everywhere scarred by landslips. Much roads at Sanhtrabary and Bexa were carried away. Owing to wave reflection objects fell in every direction.

The district of Rangpur suffered the most damage. Every brick building was irretrievably damaged and several almost completely overthrown. A few escaped with upper storey loss and lower badly cracked. Fissured opened under houses and differential subsidence of wall. Monuments of cemetery overthrown, bed of canal risen throw several feet. Central portion was seen above water. Central pier of bridge was found thrust up and broken, wells filled up with sand which was thrown out of the fissures.

In Mymensing houses were buried but seldom damaged to the ground. Many buildings were demolished in the town. Smoke was seen coming out of the ground insertion locality on eastern bank of the river. In that bank coal burnt sand and other substances come out of the earth along with sand and water. The shocks were preceded by a very grave sound like that of distant thunder and so violent that the earth swayed like a cradle with all the contents upon it. In some places houses and buildings were partially buried. In one place, a large tree sank so deep that only its branches remained above the surface of the ground.

In Dhubri houses were buried but seldom leveled to the ground. The building in most places were demolished. In the town all the two storeyed houses collapsed. In Gauhati clock at telegraph office stopped and pendulum broke. Gate pillars of many bungalows were shot off and lying on the ground. River Ganges have risen a height of 8 feet after earthquake and recovered its normal level at two and a half days. In Cherrapunje, gate pillars built of rubble stone masonry have fallen. Monuments broken across ground level. Bungalow pillars fractured and twisted but not overthrown. Landslips to a striking degree score deep valleys in Cherrapunje. In Darjeeling many houses have been badly damaged by falling in great heavy chimney stacks which crashed through the roof. A new house built of stone and mortar, upper part of western wall fell out and inner suffered badly, cracks ran through. Old tombs were thrown down partially. All public buildings in Sylhet suffered more or less. Gate pillars at government school and bungalow fell. Very few cemetery tombs have been damaged. Boiler overturned and fissures of small amount are seen throughout riverbank. In Sunamganj, it was about 30 feet broad and extended over half a mile along river bank. Paddy was damaged by upheaval of sand in some places. In Bogra, beds of river channels have been perceptibly raised here and there. The current of river ceased to flow and the villagers flocked to catch fish in the mud. Usual depth of water in Karatoya river has decreased enormously after earthquake. Several fissures from 12~18 inch were found in Sirajganj. Ground subsided 1~2 feet on side of fissures. Outpouring of sand has been greatest. Dhaka, the capital of Bangladesh, all pucca buildings were badly damaged. Some have entirely collapsed and many are uninhabitable. Some houses, club, dak-bungalow corner has fallen out. Low pillars round the racecourse has been broken off and thrown from the base. The top of the Hindu temple is broken off and shifted to one side and bent over. Water tank of an engineer's house was seen swaying and twisted. In Calcutta, earthquake proceeded by a rumbling noise. Some pinnacles of high court had been broken across and upper part twisted round. College building was seen oscillating. Tall book case fallen and heavy objects had

been thrown down. In Allahabad, violence was sufficient to displace crockery standing on tables and caused some cracks in old buildings. Hanging lamps and saddles suspended from ceiling were oscillating. Water in tubs oscillating backward and forwards.

In Nepal the shock felt distinctly at Katmandu. It was violent to cause nausea and faintness, man sit down on ground. Everyone quit their houses. Pine trees oscillating violently and roar of terror was heard. In Bhutan shock seems to have been severe. Boundary pillars at foot of the hill was broken and high land near it subsided. A portion of road was blocked by landslips. A hill was reported to have been leveled to the ground. This hill was formerly very high and its summit being covered with snow nearly all the year round. Iron bridge was reported to have collapsed. Severe shock was felt in Lhasa of Tibet but no damage. In Burma fissures of large scale was seen. Depression was formed. Broken pieces of wood observed floating on surface.

Damage photographs and sketches of this earthquake are provided in Appendix C.

2.4.4 INTENSITY RE-EVALUATION

Intensity with reference to EMS intensity scale was reestimated in this study using macro seismic data collected from contemporary documents. As a consequence of the high vulnerability of the construction of the region, the maximum intensity in destructive earthquake appears to be the same. That is at intensity X on the EMS scale all traditional houses are totally destroyed and any village would thus look equally but no more devastation at higher intensities of the scale.

From the analysis of the macroseismic data, maximum intensity was re-estimated as $I_0=X$ EMS and allocated to Tura and Shillong west. As a result of the analysis of the macroseismic data available, a new isoseismal map of the great earthquake 12th June 1897 has been constructed. The details are presented in Table 2.3. As a result of the analysis of the macroseismic data available, a new isoseismal map of the great earthquake has been constructed and is presented in Fig. 2.3.

Table 2.3 List of sites with re-estimated intensities based on EMS scale for 1897 Great Indian Earthquake

INTENSITY	SITE
X	Tura, Shillong, Goalpara, Dhubri
IX	Mymensing, Muktagacha, Rowmari, Gauhati, Rangpur, Assam Valley (Mangaldai), Coochbihar
VIII	Silchar, Kohima, Dhaka, Sirajganj, Tezpur, Cherapunji, Sylhet, Saidpur, Jalpaiguri, Comilla, Berhampur
VII	Yatung (Lhasa), Darjeeling, Noakhali, Bhagalpur, Jamalpur, Mongyr, Purnea, Faridpur
VI	Midnapore, Chittagong, Bardwan, Jessore, Barisal, Calcutta, Giridih
V	Kathmandu, Allahabad

2.4.5 MAGNITUDE AND DEPTH DETERMINATION:

Gutenberg and Richter (1954) estimated the magnitude to be 8.7 in the surface-wave scale, but recently Ambraseys (2000) revised it to 7.98. According to Oldham (1899), a movement of thrust-plane or planes, which had a maximum length of 325 km and width of 80 km, caused the earthquake. Also the depth of the principal fissure couldn't be determined, but was probably not greater than 10 km. But according to Gutenberg and Richter (1954), the depth of the earthquake was around 60 km.

2.4.6 FORESHOCK AND AFTERSHOCKS

Some tremors were said to have been noticed for a few days previously by sensitive persons but if actually perceived they must have been very slight indeed. On June 12th the severe shock commenced without any warning. At that time there was no regular system of recording earthquake.

At Shillong and Tura and all other places within the epicentral area the shocks felt during the day following the great earthquake were to be numbered by hundreds for the first few days. At Kaunia the stationmaster reported 98 shocks after the main shock, up to the end of July.

At Mymensing the meteorological reporter counted 98 while in north at Gauhati there were no less than 561. The area over which many of the larger shocks were felt in the Assam valley and north-eastern Bengal, but did not penetrate into Sylhet and Cachar or were only slightly felt at places close to their northern boundary. So the centres of the aftershocks were not symmetrically situated with reference to the axis of the range separating the Brahmaputra and Barak valley but lay for the most part towards the northern edge of these hills or under the alluvium to the North over an area which extends northwards.

2.4.7 DISCUSSION

The 12th June, 1897 earthquake constitutes the largest seismic event that occurred in Assam-Bangladesh region, this century. The study of this earthquake is of great importance for the region for a number of reasons. Firstly, it represents the largest earthquake in this particular region. Secondly, the same epicentral zone, which experienced several destructive earthquakes in the past, exhibits today many human and geographical characteristics found in different regions of the country. For these reasons a detailed study and analysis of the effect of this earthquake on the region is relevant to the whole of the North-East of Indo-Bangladesh region in terms of seismic hazard and risk evaluations. It contributes substantially to the reduction of seismic risk by suggesting new ways of improving local construction procedures, building material characteristics, strengthening and repairing of existing structures as well as layout and implementation of new urban and rural sites.

However, for a better understanding of information contained in contemporary documents, the accounts were considered in context of the period concerned; that is the political, socio-economic and demographic conditions, cultural and religious background and characteristics of the building stocks exposed to the shaking. The earthquake occurred during the British colonization period, in which many colonial settlements were founded at the end of the last centuries. The area was relatively sparsely inhabited with no large towns.

Shillong platform comprises of small, low hillocks and hill ranges forming a narrow belt along the Northern frontier of Mymensing and Sylhet district. Adjacent to Shillong platform, the East-West Dauki fault forms the tectonic boundary between Sylhet through and Shillong massif. Recent work indicates that the Dauki fault is a high angle reverse fault having a lateral component. Some major earthquake can be related to this fault. The Himalaya can be

regarded as one of the most intensely active seismic region of the world. Shillong plateau (Assam basin) in the North-East India is bounded towards North West by main boundary fault and towards North-East, South-East and South (by Dauki-tear) fault. This complex tectonics regime surrounding Shillong plateau experienced great compressive stresses and resulted in drifting of two tectonic plates (India and Burmese plate). At present the southernmost thrusting in the Himalayan-Shillong plateau region could be taking place along the southern fringe of the plateau coinciding with the Dauki fault. Current research is that shillong plateau has a thrust plane beneath it and is undergoing southward thrusting along dauki fault. So the shilling plateau and its adjoining region including North-Eastern part of Bangladesh have high seismic status.

Summarizing the result, following data has been obtained. Origin time 11h 15m (GMT); Macro seismic epicenter at 90.38° E, 25.84° N; Maximum intensity $I_o = X$ (EMS); Depth of focus = 60 km; Magnitude = 8.7.

2.5 1918 SRIMANGAL EARTHQUAKE

This study appraises one of the most destructive earthquakes that occurred in this century in the Srimangal region of Bangladesh. The Srimangal earthquake of July 8, 1918 occurred at 10h 22m 7s (GMT). The main shock, which lasted about 12s, had a devastating effect on the whole community. Two foreshocks and a series of aftershocks preceded it. The main shock was associated with ground surface fissures. Compilation and detailed study of the contemporary source documents relative to this earthquake have led to the reconstruction of its macro seismic field and reassessment of the strength of the ground shaking is possible. Intensities have been reevaluated in many sites. Maximum intensity has been re-estimated at $I_o = VIII-IX$ (EMS), assigned to Ballisera Valley and Doloj Valley and their close vicinities, an area of about 15 km radius. From the intensity data, isoseismal map has been drawn. The macro seismic epicentre has been located in the Ballisera hills near Kalighat 6 km south of Srimangal town, 91.80° North and 24.25° East. The shock was felt as far as Mymensingh 150 km away with intensity VI (EMS). The main shock was recorded by Milne seismograph. The surface wave magnitude has been calculated without station correction at 7. It is possible to reduce the effect of future seismic catastrophes through the analysis of past destructive earthquakes by suggesting new ways of improving local construction procedures, building materials, strengthening existing structure and proposing urban and rural settlement scheme.

2.5.1 INTRODUCTION

On July 8, 1918 at 10h 22m 7s (GMT), a destructive earthquake hit the region of Srimangal, Bangladesh. The most affected area lies on the tea garden area of the Ballisera Valley and Doloï Valley. The epicentral area is located at Kalighat in Ballisera valley, 6 km south of Srimangal. The main shock lasted 12 s and damaged almost every house. Details of casualties and cost of damage were not found. The earthquake was preceded by two foreshocks and was followed by a series of aftershocks with one of magnitude comparable to the main shock. Fissures in the ground were reported from various places. The earthquake affected structures in an area of about 70 km radius with intensity VI in European Macroseismic Seismic Scale (ESC, 1993). The shock was felt in a fairly large area as far east at Aijal (Monipur, India), west at Calcutta (West Bengal, India), south at Rangoon (Myanmar) and north at Katmundu (Nepal), an area of about 74000 sq. km.

The compilation and critical consideration of the macroseismic data collected from different contemporary documents has led to the re-evaluation of intensities in many sites and drawing of an isoseismal map. Maximum intensity has been reestimated at $I_0=VIII-IX$ (EMS) allocated to the tea garden area of Ballisera valley and Doloï valley and their surrounding area about 15 km radius. From these intensity data, the macroseismic epicentre has been relocated at Kalighat in Ballisera valley 6 km south of Srimangal at 91.80° North, 24.25° East. Seven seismological stations recorded the main shock. The surface wave magnitude has been calculated without station correction to be 7.

2.5.2 SOURCES OF INFORMATION

Detailed study of the macroseismic information retrieved has considerably contributed in the re-evaluation of the amount of damage experienced by man-made structures and by the ground itself. Stuart (1920) first published a report containing information regarding this earthquake. Stuart compiled a descriptive record having a scientific bearing of the earthquake. The area under study had many hills and valleys. During Stuart's field survey heavy rainfall was also encountered. Stuart collected seismographs from Bombay, Colombo, Madras, Kodaikanal, Simla, Dehradun and Rome seismic observatories. Stuart's report contains information of the event from all parts of India, where the earthquake was felt.

Questionnaire survey also was conducted and an isoseismal map was produced based on Oldham Intensity Scale (Oldham, 1899).

2.5.3 GEOGRAPHICAL ASPECTS OF THE REGION

The epicentral area of the greatest damage lay in the tea-garden area of Ballisera, Doloi and Luskerpore vallies. Throughout this area most of the houses were totally destroyed. After the earthquake, the tea-planting community were living in tottering leaf houses or hastily constructed bamboo shelters, furnished with what little furniture and crockery they had been able to dig out of the ruins of their fallen houses. Owing to the fact that there were exceedingly few pucca buildings over the area and to the fact that such as do existed vary greatly in nature and strength to resist any kind of shock. Most of the area where earthquake was violent enough to damage all or nearly all brick buildings, consist either of jungle covered hills such as Hill Tippera area or of low lying land such as in south Sylhet, practically all of which was under water at the time of earthquake due to heavy rainfall.

2.5.4 DAMAGE AND CASUALTY DISTRIBUTIONS

The macroseismic information retrieved from all the sources available to the authors were carefully analyzed and then used in the estimation of how the shock was felt and how much damage was caused to the structures and to nature in many localities. Brick buildings were limited, they belonged entirely to railway buildings and were in isolated places such as Sylhet, Moulvi Bazar, Habiganj, Kishorganj, Brahmanbaria, Agartala and buildings and factories of tea estates in the valley of south Sylhet. In Sylhet, mosque and high school buildings, which survived the 1897 earthquake, suffered heavily. The earthquake caused heavy damage to the tea garden area of the Ballisera valley and Doloi valley and their surroundings.

In Ballisera valley, all brick buildings of a tea estate at Kalighat located 6 km from Srimangal collapsed due to the main shock. Coolie lines on tea estate built mostly of sun-dried mud and thatched roofs were leveled to the ground. Usual type of planter's bungalow built of poorly burnt bricks are very thick, exceedingly heavy thatched roof also collapsed. Although steel girder frames of tea factories and certain bungalows were left standing but their brick works completely collapsed. Some steel girders were twisted and bent. Several houses were

completely destroyed and two people died under them. Walls of Kalighat church were shattered and thrown down but roof and framework were left standing.

Another tea estate at Phulchara in Ballisera valley located 4 km west of Srimangal was also badly damaged. Manager's bungalow was leveled to the ground. Every leaf house was down. Two bridge abutments settled. Many sand boils were observed. Due to the damage to brick foundation, two heavy drying machines were shifted from their bed. According to the manager of Phulchara tea estate, intensity of the earthquake was so great that he and his wife were unable to keep their feet on and was thrown to ground while bungalow collapsed. Laborers reported landslides of considerable size. Post office had fallen. Two walls of the hospital collapsed. In the Satgaon tea estate, which was on the western side of the valley, bungalow and buildings having thatch roofs without iron column were leveled to the ground. In Rashidpur (near Satgaon), railway line was seen moving in waves with a loud noise. The ground shook violently.

In Doloï and Luskerpore valleys, located south Sylhet leaf houses were leveled to the ground. Manager's bungalow was badly damaged. Madhabpur village of Doloï valley located 15 km east of Srimangal, an iron bridge running north east had some of the angle tie bars sheared and the approaches at both ends were found to settle at least 300 mm. The whole area surrounding this bridge was reported to have settled considerably. Fissures in the ground were reported from various places, most cracks of the fissures were 150 mm in length and 300 mm deep. Sand boils were observed in many places. At Kalihati two holes were noticed outside a tea factory. At Chandpur tea estate, gatepost had been cracked.

In Moulvi Bazar all brick buildings in the bazar were damaged and many of them were thrown down. Mission and sub-divisional officer's bungalows were badly damaged. High school building was completely ruined. The shock was felt from south to north.

In Habiganj damage was similar to Moulvi Bazar. The bazar and sub-divisional officer's bungalow were badly damaged. Wardrobes facing east-west overturned and eastern and western walls of some of the buildings were mostly damaged.

In Agartala all masonry buildings were heavily damaged. Domes and inner walls cracked badly. Four domes completely collapsed. Upper story of a palace seriously cracked. Ground

fissures and sand boils were observed in many places. Long fissures appeared running parallel to road or embankment. In places ground settled into small holes.

In Akhaura, part of the railway station constructed by brick collapsed, iron girder footbridge crossing railway line had some handrails bent at the ends. A 1.2 m high fully loaded iron water tank standing 7.5 m high from the ground shifted about 75 mm. Cross walls running east-west were found to have diagonal cracks. In Brahmanbaria, most buildings had some kind of cracks.

In Kishorganj, munsif's house collapsed. Jail, a brick-mud building completely collapsed. Two schools cracked badly and part of the walls fell. Railway bridge abutment cracked, and the girder moved 450 mm. Ground fissures and sand boils were observed in borrow pits beside the railway line between Mymensingh and Kishorganj.

In Fenchuganj, embankment leading up to the south end of Fenchugang bridge settled as much as 500 mm in places, leaving railway track hanging in mid air. Piers of bridge were found to have cracked below high flood level.

In Sylhet the shock was felt east west. All brick and many mosque buildings cracked badly. In one case, 7 out of 8 minarets of a mosque fell down. High school building cracked. Walls of Circuit house, which had iron framework, cracked badly. Only well built modern brick buildings had minor cracks. Cupboard facing east west was thrown out.

Damage photographs and sketches of this earthquake are provided in Appendix C.

2.5.5 INTENSITY REEVALUATION

Intensities with reference to the European Macroseismic Scale has been re-estimated in this study, using the macroseismic data collected from different contemporary documents. As a consequence of the very low strength and high vulnerability of these local structures, the maximum intensity in any destructive earthquakes seemed to be the same. That is at intensity IX of the EMS scale most of the houses will be totally destroyed. From the analysis of the macroseismic data, maximum intensity has been re-estimated as I_0 =VIII-IX (EMS), and allocated to Ballisera valley and Doloj valley. This intensity has been assigned to the zone

associated with maximum damage to structures and injuries. Intensities have been re-estimated at 61 sites and are presented in Table 2.4. As a result of the analysis of the macroseismic data available, a new isoseismal map of the 1918 Srimangal earthquake has been constructed and is presented in Fig. 2.4.

Table 2.4 List of sites with re-estimated intensities based on EMA scale for 1918 Srimangal earthquake

INTENSITY	SITE
VIII-IX	Balisera valley and Doloi valley (including Phulchara, Kalighat, Rajghat, Puttiachara, Kajurichara and Sisalbaria tea estates)
VIII	Luskerpore valley, Habiganj, MaulviBazar, Satgaon, Srimangal
VII	Agartala, Akhaura, Brahmanbaria, Kishorgonj, Sylhet, Alinagar, Shamsernagar (including Bharaura, Jagchara, Patrakhala, Madhavpur, Kanihat, Chandpur, Rashidpur, Chandichara and Deundi tea estates)
VI	Aijal, Comilla, Cherrapunji, Mymensingh, Netrokona
V	Akyab, Barisal, Calcutta, Chandpur, Chittagong, Dhaka, Faridpur, Feni, Jamalpur, Narayanganj, Noakhali, Rangamati
IV	Bhagalpur, Borjuli, Calcutta, Chinsurah, Darjeeling, Dinajpur, Dumka, Gauhati, Henzada, Krishnanagar, Kurseong, Kyaupyu, Kyauktaw, Lushai Hills, Midnapur, Pabna, Purnea, Rangpur, Nowgong, Tura, Prome
III	Bassein, Falam (Chin Hills), Allahabad, Bankipore, Daltongonj, Deoghor, Katmandu, Muzaffarpur, Prome

2.5.6 MAGNITUDE AND DEPTH DETERMINATION

The surface wave magnitude of the main shock has been calculated from the standard Prague formula using amplitude and period readings from 5 seismological station located at distances between 21° and 72°. The macroseismic epicenter of the earthquake was at 91.8°N and 24.25°E. The mean period was 12 s and derived value of M_s without station correction was 7. The magnitude has also been determined using amplitude readings. Employing the calibration formula derived by Ambraseys and Melville (1982) for Milne seismographs

$$M_s = \log(2A_t) + 1.25 \log \Delta + 4.06$$

where $(2A_t)$ is the double amplitude in mm and Δ is the distance in degrees; from this equation M_s is found to be 7.

According to Stuart (1920), depth of focus for this earthquake was between 12 km to 14 km below the ground surface. Also Gutenberg and Richter (1954) classified it to be a shallow earthquake (Class b, i.e., depth < 60 km), having a magnitude of 7.6.

2.5.7 FORESHOCKS AND AFTERSHOCKS

The main shock was followed by a number of aftershocks, some of which were strong enough to be recorded on the seismograph at Alipur Observatory, Calcutta, until July 12, 1918. These aftershocks with much less intensity than that of the main shock did not cause any further damage.

There is evidence of at least two foreshocks before the main shock on 8th July. These foreshocks occurred on July 2 at around 20h 30m (GMT) and on July 7 at around 18h 45m (GMT). The people living at Kalighat in Balisera valley and Phulchara reported the first foreshock. They felt that the beds were vibrating and also there was a loud noise at back of the houses as if something had knocked against them. The second foreshock was reported both at Balisera valley and Badarpur. In this case the noise was likened to a loud report followed by two or three thumps as if large rocks had been hurled violently against the houses.

2.5.8 DISCUSSION

The 8th July 1918 earthquake is the first felt and recorded destructive seismic event in Bangladesh. A preliminary report of this earthquake was first published in the records of the "Geological Survey of India" in 1920. For a better understanding of the information contained in contemporary documents, the accounts were considered in context of the period concerned. That is, the political and socio-economic and demographic conditions, cultural and religious backgrounds and the characteristics of the building stock exposed to the shaking. Owing to the fact that there were exceedingly few pucca buildings over the area which was seriously affected and the fact that such as do exist vary greatly in nature and strength to resist shock, it was found to be difficult to map isoseists. Most of the area where the earthquake was violent enough, damaged all or nearly all brick buildings. The area consists either of jungle covered hills such as the Tippera Hill or of low lying land such as

that seen in south Sylhet, practically all of which was under water at the time of the earthquake. Brick buildings were limited entirely to railway buildings and to those in isolated places such as Sylhet, Moulvi Bazar, Habiganj, Kishorganj, Brahmanbaria, Agartala etc. and the buildings and factories of the tea estates in the valley of south Sylhet.

A detailed study and analysis of the effects of this earthquake on the region is relevant to the whole of northeast India, in terms of seismic hazard and risk evaluations. It will contribute substantially to the reduction of seismic risk by suggesting new ways of improving local construction procedures, building material characteristics, strengthening and repairing of existing structures as well as lay out and implementation of new urban and rural sites.

Summarizing the results, following final data for the July 8 1918 earthquake has been obtained. Origin time 10h 22m 7s (GMT); instrument epicenter 91.2°E, 26.5°N (ISS); macroseismic epicenter at 91.8°E, 24.25°N; depth of focus=12 km to 14 km; maximum intensity $I_0 = \text{VIII-IX}$ (EMS); magnitude, $M_s = 7.0$.

2.6 1930 DHUBRI EARTHQUAKE

This research appraises one of the most destructive earthquakes that occurred in Dhubri since the past two centuries. On the 2nd of July, 1930 at 21h 3m 49s (GMT) the region of Dhubri was struck by destructive earthquake. According to the seismic history of the region (Indo-Bangladesh) the almost same epicentral zone has been the site of several damaging seismic events (1869,1885,1897,1918) in the last two centuries. The main shock destroyed and damaged houses, farms and public buildings. Poor quality constructions were the main cause of damage. The earthquake was followed by a series of aftershocks. It was associated with slight ground fissures in the vicinity of Lalmanirhat. Three people have been reported killed due to this earthquake. The shaking was strongly felt in the whole area encompassing Rangpur, Coochbihar, Gauhati, Cherrapunji, Kurigram, Nilphamari. It was partially perceived in western Burma, Nepal, Bhutan, Sikkim and Patna. No report of ground liquefaction was received. In order to reconstruct the macroseismic field of this earthquake, a broad investigation of contemporary documentary materials relative to this event was carried out. The result of this search have led to a re-evaluation of the extent of damage to both man made structures and nature and to an appreciation of the behaviour of the population. From the analysis of the macroseismic information retrieved, intensities have been re-estimated in

several sites. Maximum intensity has been re-evaluated at $I_0=IX$ (EMS) and allocated to Dhubri and its surrounding area. From the intensity data an isoseismal map of the earthquake has been drawn and macroseismic epicentre is located at 25.95° N, 90.04° E. The earthquake is classified as a moderate and shallow event with a focal depth of about 60 km. The surface wave magnitude is 7.1 without station correction. This earthquake has been recorded at eight stations namely Alipur, Agra, Dehra Dun, Hyderabad, Colaba, Kodaikanal, Oorgaum and Colombo.

2.6.1. INTRODUCTION

On 3rd July, 1930 at around 3 AM (local time) a destructive earthquake hit the region of north-western end of the Garo hills and the adjoining valleys of the Brahmaputra river. The earthquake was attended with disastrous results in the northern Bengal and in western Assam and felt very distinctly over a wide area extending from Dibrugarh and Manipur east of Chittagong and Calcutta in the south, Patna in the west and beyond the frontiers of Nepal, Sikkiim and Bhutan in the north an area about 825,000 sq km. The earthquake caused widespread damage in Dhubri and its surroundings, mainly associated with high vulnerability of certain types of construction. Because of the poor quality of the buildings the earthquake trapped many people under the ruins of their homes. The main shock and its aftershocks destroyed many local traditional houses. A number of bridges and culverts were damaged. The earthquake affected structures in an area of 120 km radius with intensity VII. The event was associated with slight ground fissuring. No reports of ground liquefaction were found in contemporary accounts. The earthquake occurred without any premonitory sign but was followed by a series of aftershocks with one of magnitude comparable to the main shock. It caused loss of three lives in Kurigram. The compilation and critical consideration of the macroseismic data collected from different contemporary documents has led to the re-evaluation of the intensities in many sites. Compilation and critical consideration of the macroseismic data collected from different contemporary documents has led to the re-evaluation of intensities in many sites and drawing of an isoseismal map. Maximum intensity has been re-estimated at $I_0=IX$ (EMS) and allocated to Dhubri and their surroundings in an area of 23 km radius. From the intensity data the macroseismic epicentre has been relocated slightly west of Dhubri at 25.95° N, 90.04° E. The main shock was widely recorded by eight seismological stations. The surface wave magnitude has been calculated without station

correction as 7.1. A detailed investigative report of this earthquake was published by Gee (1934).

2.6.2. GEOGRAPHICAL ASPECTS OF THE REGION

The sensible zone of earthquake includes widely contrasting types of topography and geology. The epicentral tract near the town of Dhubri and other areas badly affected, comprise a portion of the alluvial plain country which is traversed by the lower courses of the Brahmaputra and Ganges river and by their tributaries. To the North, in the outer part of the sensitive zone, rise the outer ranges of Nepal, Dirjeeling, Sikkim, Bhutan and Himalayas. To the North-East and East-North-East of Dhubri, the higher reaches of the Brahmaputra river traverse a wide alluvial valley, narrowing Eastwards and dotted by number of prominent hills, whilst the more distant Southeastern areas include the alluvial plains of Mymensing and Sylhet. Between this two latter tracks, East of the Brahmaputra are the jungle clad ridges of the Garo hills rising to well over 4000 feet; these continue Eastwards to link up with the Khasi and Jainta hills of the Shillong plateau.

Fortunately from a point of view of estimating the intensity of the earthquake shock, a large portion of the epicentral and adjoining tract, the eastern Bengal railway line, the station and the railway cantonments were built wholly of brick masonry of a fairly standard type, have afforded very useful data in demarcating the isoseist of the main shock. These populated areas comprise the alluvial tract lying between the Ganga and the Brahmaputra rivers. To the South East of the Brahmaputra, within the jungle covered uplands of the Garo hills, the town of Tura, lying a short distance outside the epicentral tract, and still more distant station of Goalpara are the only place of sufficient type and size from which the intensity of the shock can be estimated. With few exception of Rowmari and Manikarchar where several brick building exist, the villages are mainly constructed of light bamboo covered with mud plaster and supported on a wooden framework with post drive into masonry plinth or alluvial foundation. Upon this house the vibrations of the earths crust resulting from the main shock, would have left few recognizable imprints.

2.6.3. DAMAGE AND CASUALTY DISTRIBUTIONS

The macroseismic information extracted from all the sources available to us have been used in the re-assessment of the effects on the affected region of this event. A detailed study of the macroseismic field has led to a comprehensive re-evaluation of how much damage was caused to man made structures and to the ground itself. It is revealed from the documentary materials that as in the past earthquake in northeastern region of India mud, stone and unreinforced masonry buildings totally collapsed or experienced heavy damage. Taking into account the size of the earthquake, the time of occurrence and the low quality and vulnerable state of the structure, it is amazing that only three casualties were reported. The earthquake caused total destruction or heavy damage to most of the constructions in the area around the villages of Dhubri.

In Dhubri a few brick masonry building escaped; majority were badly cracked and partially collapsed. Some of these are the house of a local zamindar, treasury building, charity hospital and a brick built mosque with galvanized iron roof.

At Gauripur four miles west of Dhubri the railway station was seriously affected by shock, the ground upheaving resulted in large cracks in floors and walls of the building. The railway line was seriously affected, embankments were fissured and partially collapsed. Cracks were formed in masonry culverts and bridges. Numerous fissures were formed and from them sand and water spouted upwards to a height of several feet. Wells were overflowed and silted up by the sandy alluvium from below. Level of the Brahmaputra river have risen from 2~3 feet. The main shock was preceded by low rumbling sound. Monuments and gate pillars were overthrown.

In Lalmanirhat very few buildings escaped undamaged. Out of total 242 buildings affected, 140 were damaged more or less seriously of which five staff quarters were condemned and rendered temporarily uninhabitable. Definite lines of ground fissures, running E-W occurred in different parts of the colony. Traffic superintendent's bungalow, an old brick building was seriously damaged. Railway track suffered distortion in several places and a number of culverts and bridges were slightly damaged.

In Rangpur the earthquake caused extensive damages to almost all the public and private masonry buildings. Railway and public roads are reported to have sunk at some places. All the walls of the civil and criminal court buildings are cracked and damaged. Post office, zilla school, charitable dispensary, the jail and circuit houses are badly damaged. Within the town, fissures following E-W traversed the alluvium and were accompanied by the spouting of sand and water. Within the bazaar area a number of buildings partially collapsed. In King Edward memorial hall a brick building was suffered upheaval to the extent of several inches. The railway station was traversed by large cracks. Certain recently constructed houses suffered only minor damage.

In Coochbihar no fissures were formed in alluvium. The surface of ground was thrown into a succession of waves. Old brick buildings suffered decay and were badly shattered and in some cases partially collapsed. New structures were undamaged. Revenue and treasury offices and vice president's office all fairly old brick masonry structures were very seriously affected by the main shock. Numerous large cracks traversed the structures. Bricks and turrets were dislodged from the upper parts of the buildings and large masses of plaster fell within.

In Tura all the brick buildings of the town are constructed of split bamboo of mud plaster mounted on a wooden framework. The relative immunity of those buildings which were not fixed to the ground but were free to move as a whole with their own natural period of vibration. The oscillation resulted in the shearing of wooden supports marked distortion of the walls, large falls of plaster and the overthrow of furniture inside the building. Many government bungalows were seriously affected. The jail had been affected by the slipping of sub soil and underlying decomposed sandstone down the valley slope.

In Nilphamari sub-jail has suffered most severely. Roof of the outer barack partially tumbled down and wall cracked. Quarter of sub-divisional officer, high school building, local big mosque suffered very badly. In Kurigram almost all walls of the court buildings are cracked, damaged and leaked badly during rain. Post office and training hostel were badly damaged.

In Goalpara circuit house, post office and sub-divisional officer's bungalow built of mud-plaster supported by wooden posts continued down into brick masonry plinth. During shock plaster fell in many places and walls suffered minor damage, brick dislodged from certain

panels. Brick masonry wall enclosing the jail was cracked and slightly displaced. No ground fissures were reported. In Gauhati the main buildings of town are constructed of mud plaster, few semi-pucca with brick masonry. These suffered minor injury-only the fall of plaster. Few old buildings were found with numerous masonry cracks over window and door arches. Jail wall was cracked and displaced. Judicial and revenue record rooms badly damaged and walls separated.

In Shillong the shock is of sufficient intensity. Vibration was sufficient enough to result in dislodgment of vases within the building. In few old structures- falls of plaster took place, at Parsonage cracks formed near corners of masonry plinth. In Cherrapunji missionary houses, church, school and several government building built of mud-plaster on masonry plinth suffered slight plaster fall. Cracks were found in tombstone. Three monuments in the forms of stone masonry pillars were damaged. In each case mortar of masonry had decayed considerably. In Nowgong, Sylhet and Chittagong no appreciable damage of buildings and bridges were observed. General damage was slight.

Damage photographs and sketches of this earthquake are provided in Appendix C.

2.6.4. INTENSITY RE-EVALUATION

Intensity with reference to EMS intensity scale was reestimated in this study using macro seismic data collected from different contemporary documents. As a consequence of the very low strength and high vulnerability of the construction of the region, the maximum intensity in any destructive earthquake appears to be the same. That is at intensity XI on the EMS scale all traditional houses are totally destroyed and any village would thus look equally but no more devastating at higher intensities of the scale.

From the analysis of the macroseismic data, maximum intensity was reestimated as $I_0=IX$ (EMS) and allocated to Dhubri. The intensity was assigned to the zone associated with maximum damage to structures and injuries. Intensities were re-evaluated at 56 sites and are presented in Table 2.5. As a result of the analysis of the macroseismic data available, a new isoseismal map of the earthquake, 3rd July, 1930 has been constructed and shown in Fig. 2.5.

Table 2.5 List of sites with re-estimated intensities based on EMS scale for 1930 Dhubri earthquake

INTENSITY	SITE
IX	Dhubri, South-East of Brahmaputra, North-West Garo hill
VIII	Lalmanirhat, Rangpur, Nilphamari, Kurigram, Tura, Rowmari, Bilaspara
VII	Coochbehar, Alipur dours, Buxafort, Goalpara, Nalbari, Bogra, Parbatipur, Dinajpur
VI	Shillong, Gauhati, Cherrapunji, Mymensing, Netrokona, Jalpaiguri, Natore, Rajshahi, Sirajgonj, Dirjeeling, Purina, Mongaldai
V	Faridpur, Dhaka, Brahmanbaria, Hoogly, Jessore, Pabna, Dumka, krishnanagar, Sylhet, Barisal, Haflong
IV	Midnapore, Raniganj, Dhanbad, Patna, Calcutta, Chittagong, Giridih, Sibsagar, Monipur
III	Akyab, Balasor, Katmandu, Lohardaga, Digboi, Lido

2.6.5. MAGNITUDE AND DEPTH DETERMINATION

According to Gee (1934), no clear picture can be found regarding depth of this earthquake. Gupta et al (1986) reported the depth of this earthquake as 60 km. Magnitude of this earthquake has been reported by Gutenberg and Richter (1954) as 7.1(Ms).

2.6.6 FORESHOCK AND AFTERSHOCK

There appears to be no evidence of foreshocks preceding the main Dhubri earthquake. Reports indicate that the disturbance took place suddenly after a considerable period of quiescence of seismic activity in these regions. Numerous relatively minor disturbances followed the main earthquake and although the frequency of these aftershocks had diminished very considerably, they were experienced at regular intervals throughout the July 1930. During the 24 hours that succeeded the main earthquake on 3rd July, a total of 54 separate shocks were recorded. Almost all of these were experienced at Dhubri; a number of earthquakes were felt at Gauhati whilst the one recorded at 5-49 A.M. was felt at much

greater distances from the Dhubri epicentre. On the 4th and 5th July 1930, 37 and 34 shocks respectively were recorded. Again a large number of these appeared to have originated near epicenter of the main earthquake, others not registered at Dhubri suggest an origin higher up the Brahmaputra valley in the vicinity of Gauhati. All together around 400 aftershocks were observed in this area for the next three years, i.e. until the end of June 1933.

2.6.7 DISCUSSION

The Dhubri earthquake of 3rd July (local time) is one of the largest seismic events felt and recorded in Northwestern zone of Garo hill and adjoining valleys of Brahmaputra river close to the Indo-Bangladesh border. Dhubri and its surrounding areas sustained major damage during many past earthquakes, particularly the 1897 Great Indian.

The reconstruction of the macroseismic field of this event is of great importance for many reasons. First, it represents one of the strongest felt and recorded earthquake in Dhubri and its vicinity. Secondly, the same epicentral zone and its surroundings, which experienced destructive earthquakes in the past, exhibits today many of the human and geographical characteristics, found in other parts of the country. For the presence of Dauki, Dhubri and other fault systems in this region, this area experienced several devastated earthquakes in the last century. For these reasons a detailed study and analysis of the effect of this earthquake on the region is relevant to the whole of the northwestern Assam, Sylhet, Mymensing, Rangpur region in terms of seismic hazard and risk evaluations. It contributes substantially to the reduction of seismic risk by suggesting new ways of improving local construction procedures, building material characteristics, strengthening and repairing of existing structures as well as layout and implementation of new urban and rural sites.

However for a better understanding of information contained in contemporary documents, the accounts were considered in context of the period concerned; that is the political, socio-economic and demographic conditions cultural and religious background and characteristics of the building stocks exposed to the shaking.

Summarizing the results, following final data for the July 2 1930 earthquake has been obtained. Origin time 21h 3m 49s (GMT); instrument epicenter 90°E, 25.5°N; macroseismic

epicenter at 90.04°E , 25.95°N ; depth of focus=60 km; maximum intensity $I_0 = \text{IX}$ (EMS); magnitude, $M_s = 7.1$.

2.7 SUMMARY

In this chapter five historical earthquakes have been reevaluated and their intensity have also been recalculated based on European Macroseismic Scale (1992). Also isoseismal maps of these five events namely 1869 Cachar earthquake, 1885 Bengal earthquake, 1897 Great Indian earthquake, 1918 Srimangal earthquake and 1930 Dhubri earthquake are completely revised and reproduced.

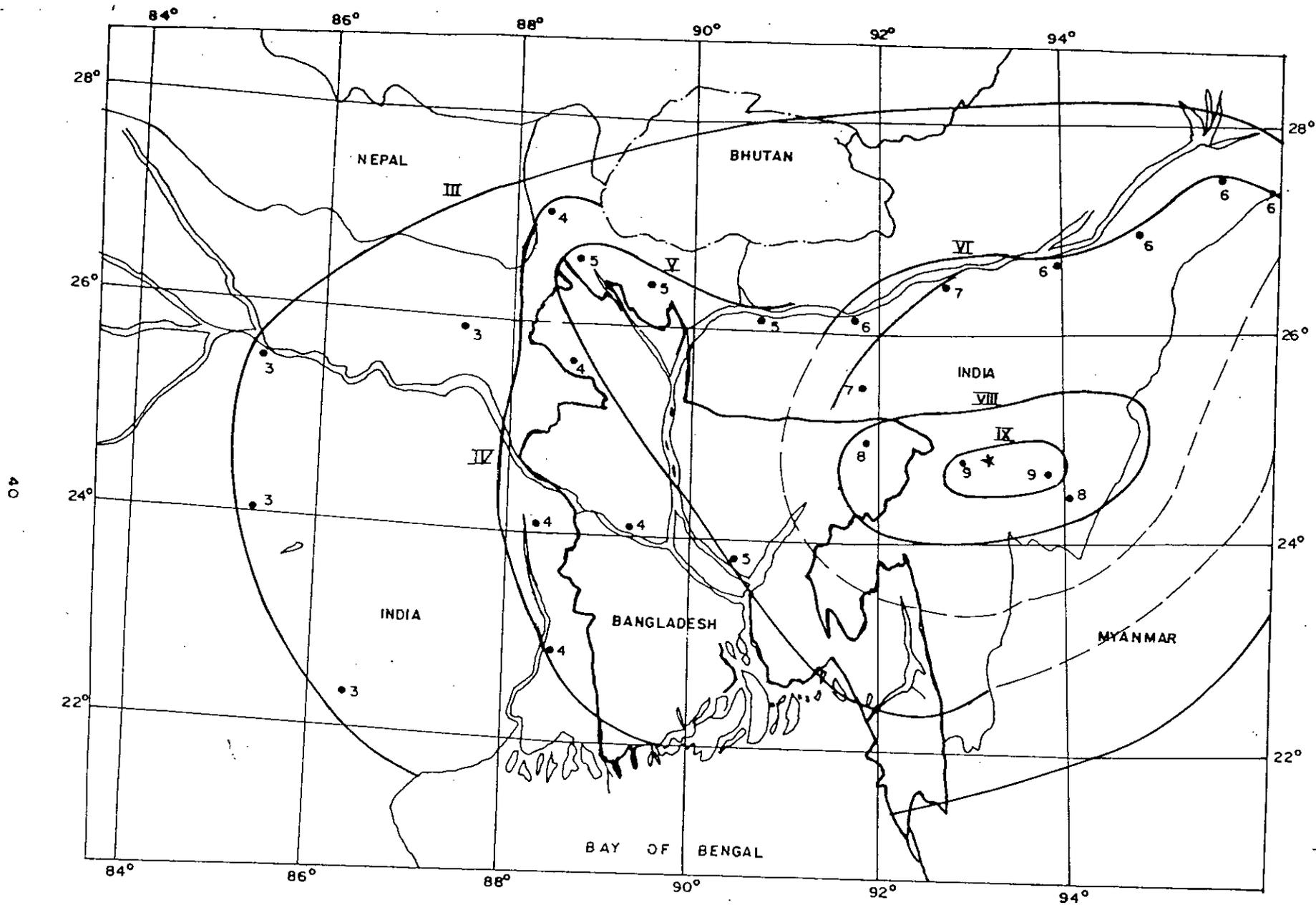


FIG. 2.] ISOSEISMAL MAP (IN TERMS OF EMS SCALE) OF THE MAIN SHOCK OF JANUARY 10, 1869 EARTHQUAKE. THE STAR SHOWS THE MACROSEISMIC EPICENTRE.

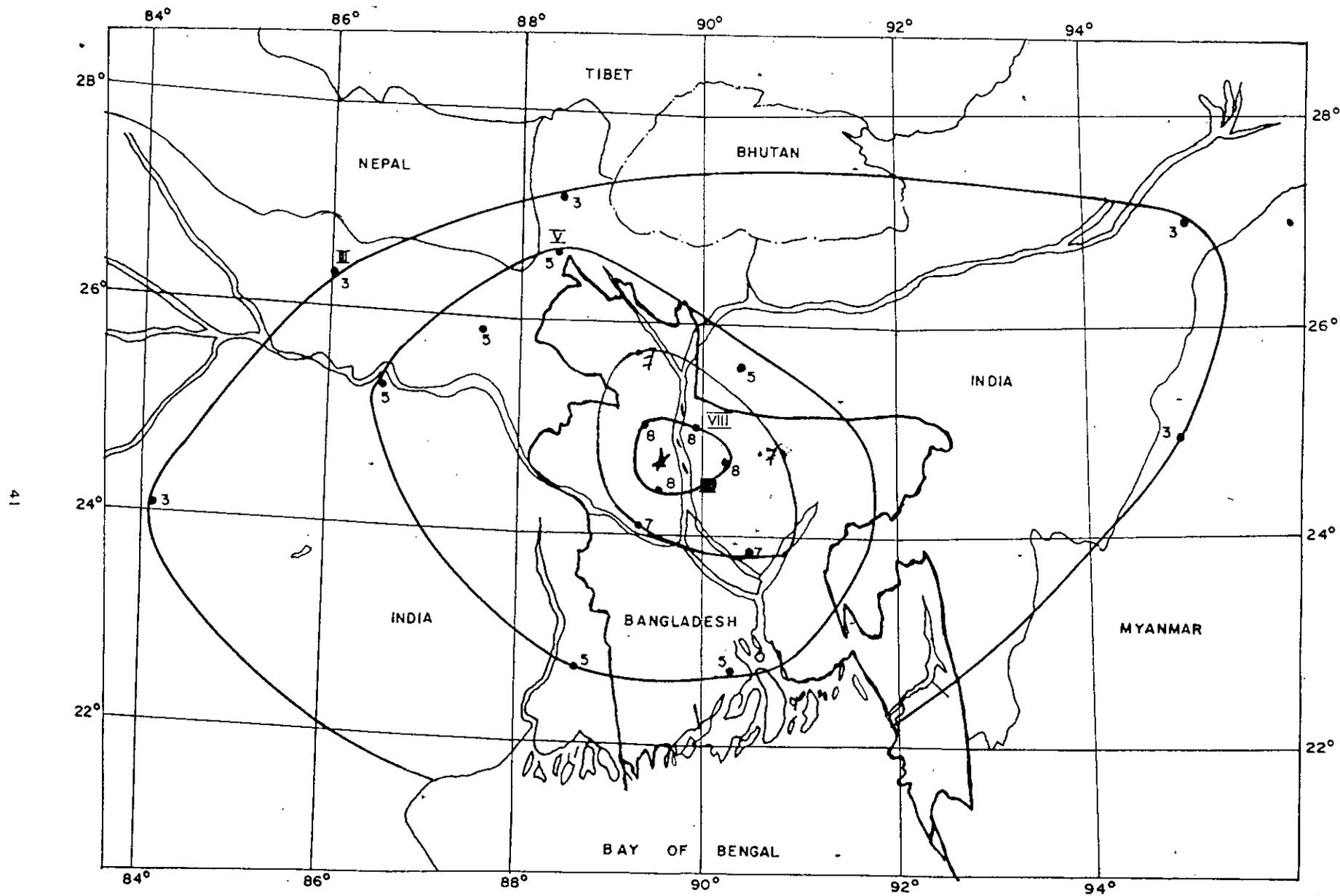


FIG. 2.2 ISOSEISMAL MAP (IN TERMS OF EMS SCALE) OF THE MAIN SHOCK OF JULY 14, 1885 EARTHQUAKE. THE STAR SHOWS THE MACROSEISMIC EPICENTRE. THE SQUARE SHOWS

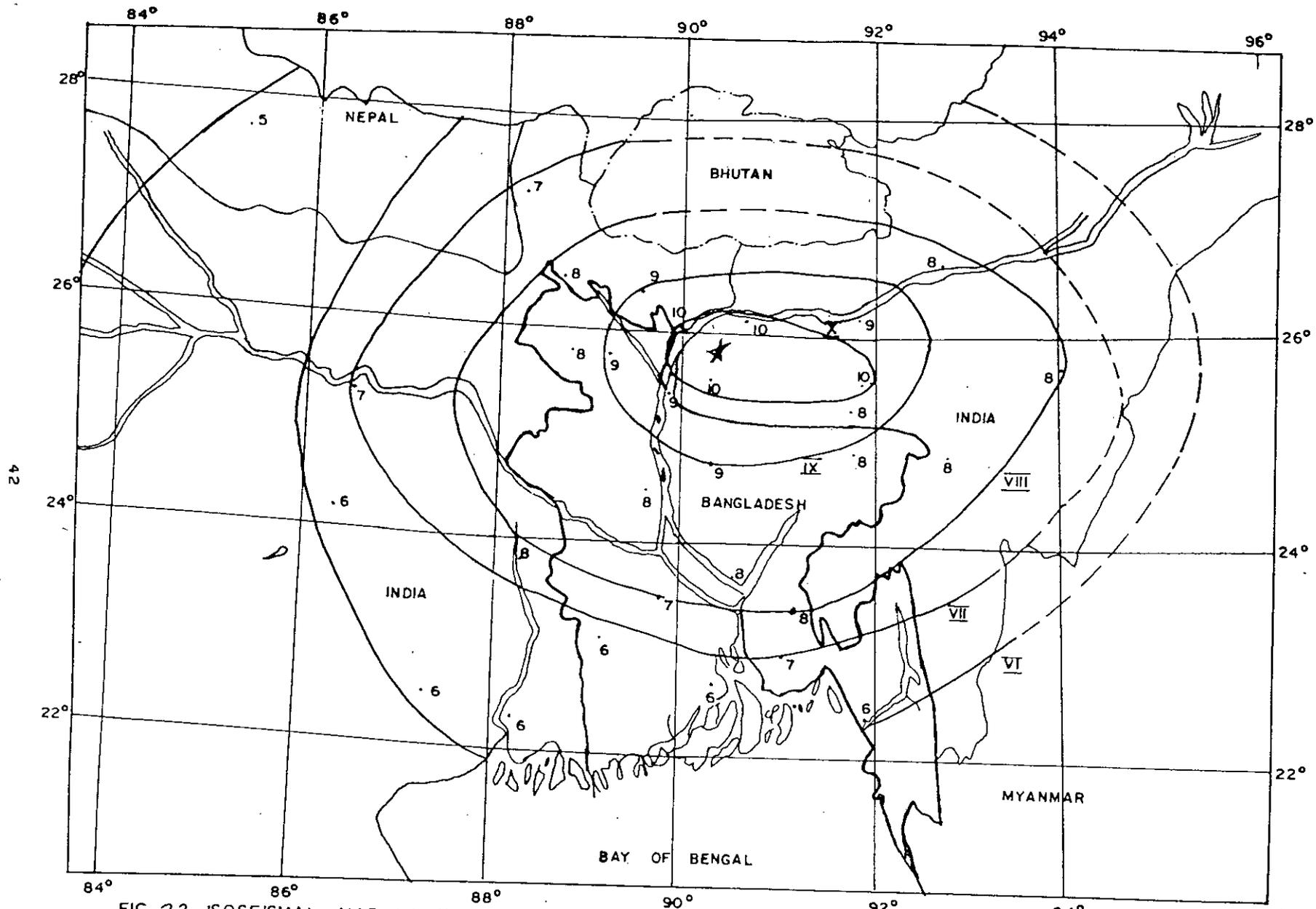


FIG. 2.3 ISOSEISMAL MAP (IN TERMS OF EMS SCALE) OF THE MAIN SHOCK OF JUNE 12, 1897 EARTHQUAKE. THE STAR SHOWS THE MACROSEISMIC EPICENTRE.

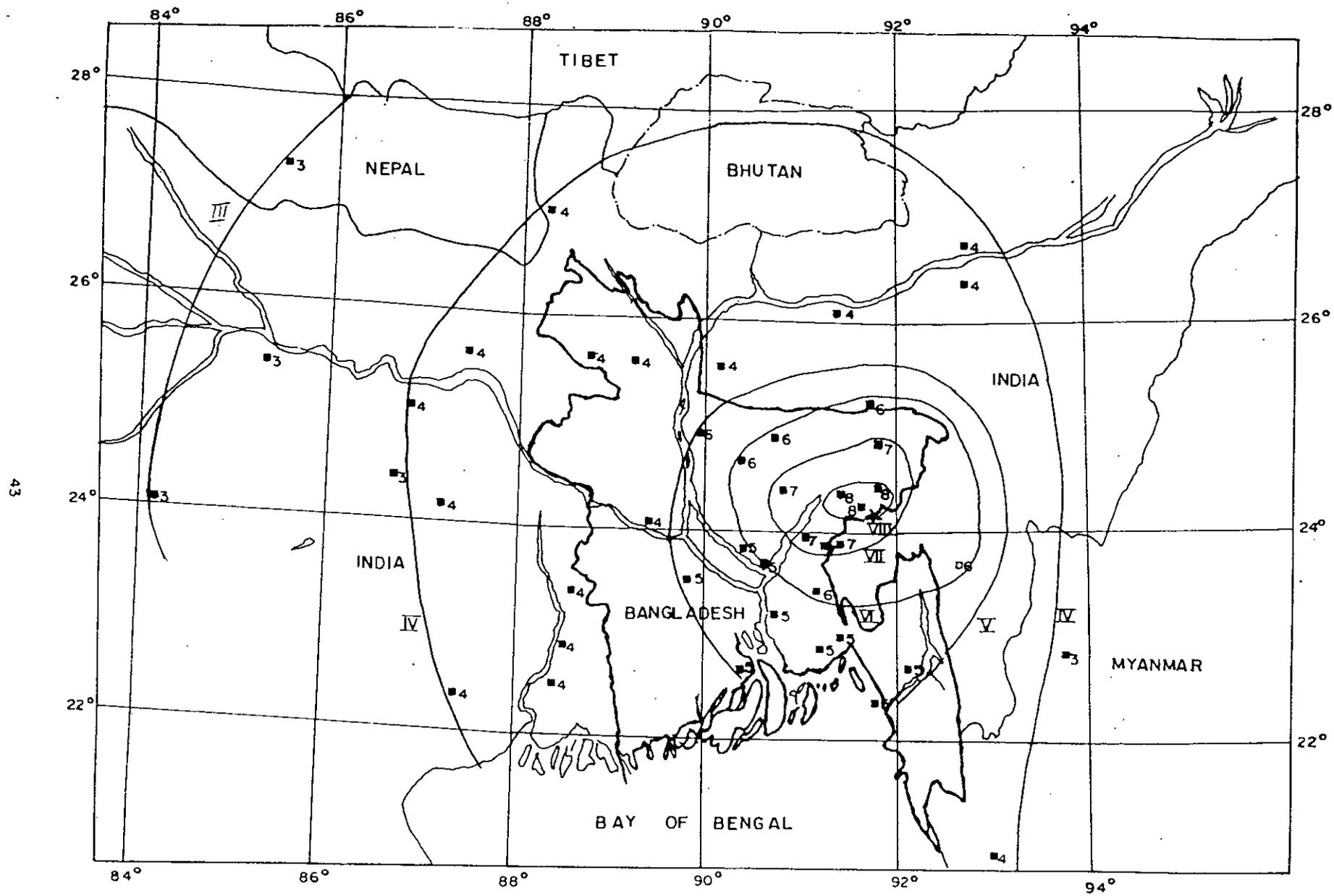


FIG. 2.4 ISOSEISMAL MAP (IN TERMS OF EMS SCALE) OF THE MAIN SHOCK OF JULY 8, 1918 EARTHQUAKE. THE STAR SHOWS THE MACROSEISMIC EPICENTRE.

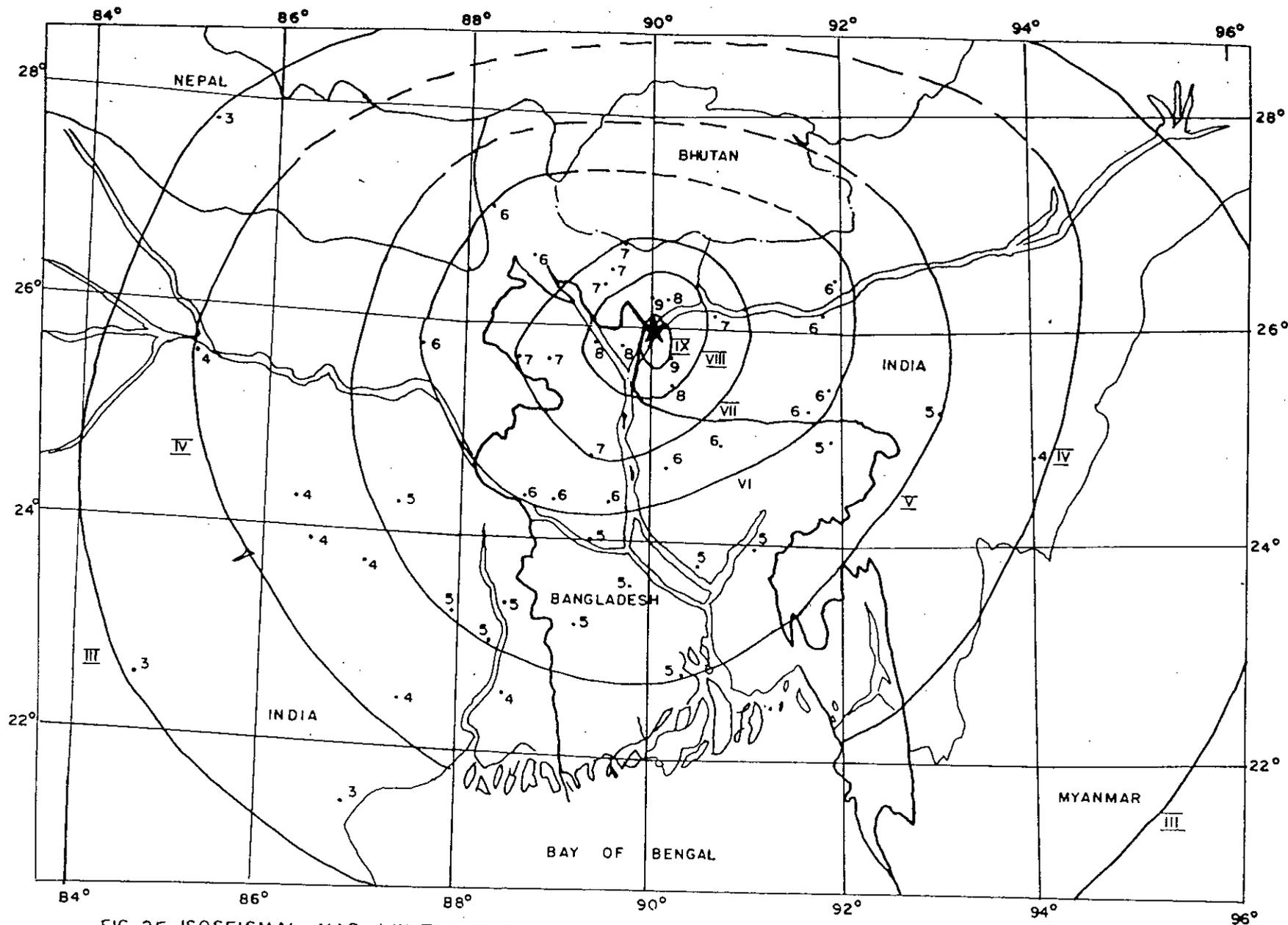


FIG. 25 ISOSEISMAL MAP (IN TERMS OF EMS SCALE) OF THE MAIN SHOCK OF JULY 2, 1930 EARTHQUAKE. THE STAR SHOWS THE MACROSEISMIC EPICENTRE.

CHAPTER THREE

MAGNITUDE-INTENSITY AND INTENSITY- ATTENUATION RELATIONSHIPS

3.1 GENERAL

This chapter presents the results of a study of the magnitude-intensity and intensity-attenuation relationships for earthquakes in Bangladesh and its surrounding region.

The purpose of this study is to present predicting models for magnitude-intensity and intensity-attenuation for earthquakes in Bangladesh and its surrounding region. Despite the increase in numbers of strong-motion accelerographs, intensity continues to be a necessary measure of size of ground shaking in earthquakes. When evaluated consistently for a large number of earthquakes to represent the seismic activity of a region, macroseismic intensity, as other semi-empirical measures may disclose regular isoseismal models, which can be taken to represent a simple radiation pattern associated with the point source. This approach remains very practical for an efficient evaluation of the interaction between earthquakes and environment and thus for seismic hazard and risk. The attenuation of intensity with epicentral distance constitutes the cornerstone parameter when assessing seismic hazard at a given site. Also, spatial distribution of intensity may be used to assign magnitudes to earthquakes without instrumental data but for which isoseismal radii and intensities are known. Both relationships namely intensity-attenuation and magnitude-intensity are obtained by deriving empirical correlations between intensity, magnitude and epicentral distance for earthquakes for which instrumental magnitude as well as isoseismal maps are available. For this purpose, an earthquake data set sample for the area was completely revised.

3.2 THE DATA

The zones under consideration consist of Bangladesh and its adjoining region, which are shown, in Fig. 3.1. The zone is situated in the northeast part of the Indian subcontinent where earthquakes frequently occur. This region lies along the border of Eurasian and Indo-Australian plates.

The data used in the analysis are based on a selection that involves not only the most important from the human point of view but also the most revealing earthquake that have occurred in this region during the last two centuries. These events which are listed in Table 3.1, are considered as a representative sample of the seismicity in the region under consideration; they cover fairly well the seismic activity of Bangladesh-India-Myanmar region in these two centuries. Most of these events have had their macroseismic data completely re-evaluated using primary sources of information which consist of published technical studies, press reports, historical records, official reports and also unpublished material. Intensities have been re-estimated anew using standard criteria according to the European Macroseismic Scale (ESC, 1993) intensity scale and surface wave magnitudes M_s have been determined by using instrumental data.

The data sample includes 18 selected isoseismal event maps; among these, 10 were constructed anew in this study. In order to obtain a more representative sample for the correlation, eight other isoseismal events were adopted from the existing maps (Agrawal, 1986; Gosavi et. al.; Middlemiss, 1906; SEASEE, 1989; Tandon, 1954; Tandon and Mukherjee, 1956). The average radius of each isoseismal was determined from the radii measured in 16 directions at 22.5° intervals of the compass. Isoseismals with no reliable data were disregarded from the regression analysis. The isoseismal maps of 5 reestimated earthquakes are shown in chapter two and the rest 13 isoseismal maps are presented in Appendix D. The mean epicentral radii D_i for all the isoseismals of the events chosen and used in the regression analysis are given in Table 3.1.

Table 3.1 Selected earthquakes in Bangladesh and neighboring region considered in the study

Event no.	Date	Macroseismic Epicentre		M _s	M _b	Depth (km)	Mean radius (km) of isoseismals (EMS)								Site
		Latitude	Longitude				D ₃	D ₄	D ₅	D ₆	D ₇	D ₈	D ₉	D ₁₀	
1	24 August 1858	18.72° N	95.27° E	6.5	-	-	-	-	-	-	186	112	65	-	Sandoway.MR
2	10 January 1869	24.79° N	93.17° E	7.5	-	48	543	-	342	247	-	115	44	-	Cachar.ID (NE)
3	14 July 1885	24.70° N	89.55° E	7.0	-	72	467	-	244	-	-	47	-	-	Sirajganj.BD (NE)
4	12 June 1897	25.84° N	90.38° E	8.7	8.0	60	-	-	-	467	342	266	138	69	Assam.ID (NE)
5	29 September 1906	23.19° N	88.59° E	5.5	-	-	185	132	-	66	-	-	-	-	Calcutta.ID (PI)
6	23 May 1912	21.75° N	96.38° E	7.9	-	25	497	386	-	285	195	-	-	-	Mandalay.MR
7	8 July 1918	24.16° N	91.75° E	7.6	-	14	-	401	190	130	65	28	-	-	Srimangal.BD (NE)
8	2 July 1930	25.95° N	90.04° E	7.1	7.0	60	637	449	318	212	121	67	23	-	Dhubri.ID (NE)
9	15 January 1934	26.47° N	85.92° E	8.3	7.7	33	1274	-	933	562	340	-	190	113	Bihar.ID-NP (GB)
10	16 August 1938	23.05° N	94.75° E	7.2	7.0	60	-	-	-	-	115	58	-	-	Mawlaik.MR
11	15 August 1950	28.79° N	95.62° E	8.6	8.5	25	-	966	690	530	315	275	225	150	Assam.ID (NE)
12	21 March 1954	25.86° N	94° E	7.4	-	180	805	606	459	316	-	-	-	-	Manipur.ID (NE)
13	8 July 1975	25.58° N	92.60° E	6.7	6.5	112	434	226	101	28	-	-	-	-	Assam.ID (NE)
14	30 December 1984	24.72° N	92.90° E	5.7	5.5	4	-	-	-	10	6	-	-	-	Cachar.ID (NE)
15	20 August 1988	26.59° N	86.65° E	6.6	6.4	65	-	-	-	154	121	72	-	-	Bihar.ID-NP (GB)
16	8 May 1997	24.90° N	92.31° E	5.6	5.6	35	330	-	185	49	21	-	-	-	Sylhet.BD-ID (NE)
17	21 November 1997	22.07° N	92.75° E	5.3	6.0	56	-	230	136	65	29	-	-	-	BD-MR
18	22 July 1999	21.61° N	91.96° E	4.2	5.1	10	-	-	12	8	3	-	-	-	Moheshkhali.BD

Note: BD: Bangladesh; ID: India; MR: Myanmar; NP: Nepal; GB: Ganga Basin; NE: Northeast India; PI: Peninsular India.

*According to Bilham and England (2001), this is 8.1

3.3 MAGNITUDE-INTENSITY RELATIONSHIPS

The magnitude-intensity relationships model procedure used in this study are based on the form of expression proposed by Ambraseys (1985b). The general form of the magnitude-intensity correlation is expressed by:

$$M_{sc} = A_1 + A_2(I_i) + A_3(R_i) + A_4 \log R_i + \sigma P \quad (3.1)$$

where M_{sc} is the predicted macroseismic magnitude, R_i is the hypocentral distance that corresponds to the average epicentral radii $D_i = (R_i^2 - h_o^2)^{1/2}$, in km of isoseismal of intensity I_i and h_o which represents the mean focal depth for the whole data set used and is a constant determined by searching to minimize the sum of squares of the residuals. σ is the standard deviation of M_{sc} and the constant P takes a value zero for 50 percent probability that the predicted parameter will exceed the real value and one for 84 percent probability.

One of the results of the revision of the data set presented in Table 3.1 is the derivation of a relationship from which the surface-wave magnitude can be estimated from macroseismic information. This can be achieved by fitting the pairs I_i and R_i with their corresponding surface wave magnitude M_s to equation (3.1).

The result of the regression analysis of the whole data set of Bangladesh and its surrounding region, which consists of 18 events and 74 pairs (I_i , D_i), is

$$M_{sc} = -3.688 + 0.513j^{-1} \sum (I_i) - 0.000003j^{-1} \sum (R_i) + 3.356j^{-1} \sum (\log R_i) \pm 0.59P \quad (3.2)$$

where $j \geq 1$ is the number of isoseismals available for the determination of the mean value of the equivalent surface wave magnitude M_{sc} of a particular earthquake and $R_i = (D_i^2 + (52.56)^2)^{1/2}$ in km. The curves of macroseismic magnitudes M_{sc} predicted by equation (3.2) for intensities III~IX and distance R are shown in Fig. 3.2. A comparison between the surface-wave magnitude M_s calculated from instrumental data for the events and the values of M_{sc} predicted from equation (3.2) is shown in Fig. 3.3, i.e. $M_s = -0.542 + 1.075(M_{sc})$ with a standard deviation of 0.563 and a coefficient of correlation of 0.90.

Using the same procedure, equation (3.1) is now fitted to the selected northeastern and Ganga-Basin data set listed in Table 3.1, 55 pairs of (I_i , D_i) corresponding to 12 events. The regression analysis gives the following results:

$$M_{sc} = -1.487 + 0.471j^{-1} \sum_j (I_i) + 0.00043j^{-1} \sum_j (R_i) + 2.512j^{-1} \sum_j (\log R_i) \pm 0.45P \quad (3.3)$$

with $R_i = (D_i^2 + (57.5)^2)^{1/2}$.

Figure 3.4 shows the curves of macroseismic magnitudes M_{sc} predicted by equation (3.3) for intensities III~IX and distance R. A comparison between the surface-wave magnitude M_s calculated from instrumental data for the events and the values of M_{sc} predicted from equation (3.3) is shown in Fig. 3.5, i.e. $M_s = -0.686 + 1.09(M_{sc})$ with a standard deviation of 0.451 and a coefficient of correlation of 0.91.

Also using the same procedure, equation (3.1) is now fitted to the selected northeastern data set listed in Table 3.1, 46 pairs of (I_i, D_i) corresponding to 10 events. The regression analysis gives the following results:

$$M_{sc} = -1.673 + 0.501j^{-1} \sum_j (I_i) + 0.00063j^{-1} \sum_j (R_i) + 2.510j^{-1} \sum_j (\log R_i) \pm 0.46P \quad (3.4)$$

with $R_i = (D_i^2 + (59.2)^2)^{1/2}$.

Figure 3.6 shows the curves of macroseismic magnitudes M_{sc} predicted by equation (3.4) for intensities III~IX and distance R. A comparison between the surface-wave magnitude M_s calculated from instrumental data for the events and the values of M_{sc} predicted from equation (3.4) is shown in Fig. 3.7, i.e. $M_s = -0.624 + 1.08(M_{sc})$ with a standard deviation of 0.449 and a coefficient of correlation of 0.91.

A comparison of the magnitude-intensity relationships in Northeast India with Northeast India and Ganga-Basin and the whole data set for intensities V, VI and VII are, respectively, plotted in Figures 3.8 (a), (b) and (c) which show clearly that the correlation present a general similarity.

3.4 INTENSITY-ATTENUATION RELATIONSHIPS

The attenuation relationships for EMS intensity with distance for Bangladesh and its surrounding region are estimated. Using the earthquake data set listed in Table 3.1, the attenuation expression may also be derived by solving equation (3.1) for the intensity I. Thus the intensity, I, may be expressed in the general form

$$I = B_1 + B_2(M_s) + B_3(R) + B_4 \log R + \sigma P \quad (3.5)$$

Where B_1 , B_2 , B_3 and B_4 are coefficients to be determined, M_s is the recalculated surface wave magnitude, R is the hypocentral distance that corresponds to the mean epicentral radius $D_i = (R_i^2 - h_o^2)^{1/2}$ of isoseismal I_i in km, and h_o , σ , and P are as defined previously. Equation (3.5) is a general form of expression used for the attenuation of peak ground acceleration, a_{max} where $\log a_{max}$ is replaced by the intensity I , as in Joyner and Boore (1981) and Ambraseys and Bommer (1991). The coefficients B_1 , B_2 , B_3 and B_4 are determined by fitting equation (3.5) to the earthquake data set M_s and selected (I_i, D_i) pairs listed in Table 3.1. A two-stage regression analysis is used here to evaluate the coefficients.

The regression analysis for the whole data set, which consists of 74 (I_i, D_i) pairs corresponding to 18 events, gives the following mean attenuation expression:

$$I = 8.378 + 1.283(M_s) - 0.0007483(R) - 4.9(\log R) \pm 0.93P \quad (3.6)$$

Next considering northeastern and Ganga-Basin data set, which consists of 55 (I_i, D_i) pairs corresponding to 12 events, gives the following mean attenuation expression:

$$I = 5.602 + 1.546(M_s) - 0.00121(R) - 4.501(\log R) \pm 0.82P \quad (3.7)$$

Again considering northeastern data set, which consists of 46 (I_i, D_i) pairs corresponding to 10 events, gives the following mean attenuation expression:

$$I = 5.35 + 1.48(M_s) - 0.00179(R) - 4.171(\log R) \pm 0.79P \quad (3.8)$$

In Figures 3.9(a) to 3.9(d), the data sample (I_i, D_i) of four events used in the regression analysis are plotted against the mean attenuation curve for the whole data set of Bangladesh and its surrounding region. These four events are respectively, the 8.7 M_s Great Indian 1897, the 7.1 M_s Dhubri 1930, the 6.6 M_s Bihar-Nepal 1988 and the 5.3 M_s Bangladesh-Myanmar 1997 earthquakes. The data points for these earthquakes show good agreement with the proposed intensity-attenuation relationships for Bangladesh and its surrounding region.

A comparison among the intensity-attenuation relationships for the whole data set and northeastern data set, plotted for four magnitudes 5, 6, 7 and 8 is shown in Figure 3.10. This figure clearly shows that intensity-attenuation curves are very similar for higher magnitudes, but for lower magnitudes there exist some dissimilarity.

3.5 SUMMARY

The findings of this study constitute the first intensity-attenuation and magnitude-intensity model derived for Bangladesh and its surrounding region (Bhutan, India, Nepal and Myanmar) using macroseismic data. The earthquake data sample involved in this analysis was completely revised. The derived relations, which represent the equivalent surface-wave magnitude, M_{sc} in terms of the effects felt, may be used to assign magnitudes to events which have no instrumental data but for which isoseismal radii and intensities are available. It was found that the intensity-attenuation models of the zone fit the macroseismic data quite well. However, it must be kept in mind that these relationships were derived using earthquakes with surface-wave magnitudes in the range $4.2 \leq M_s \leq 8.7$; therefore they should be used with certain caution near the limits of these ranges.

The advantage of the use of equations 3.2, 3.3, 3.4, 3.6, 3.7 and 3.8 is that epicentral intensities are not needed and the magnitude-intensity relationships may be used to assign magnitudes to earthquakes in regions of sparse population density. Although all the relationships derived in this work show a certain consistency with the data set, it is clear that more data are needed before a final conclusion about the intensity-attenuation rate in the study region can be drawn.

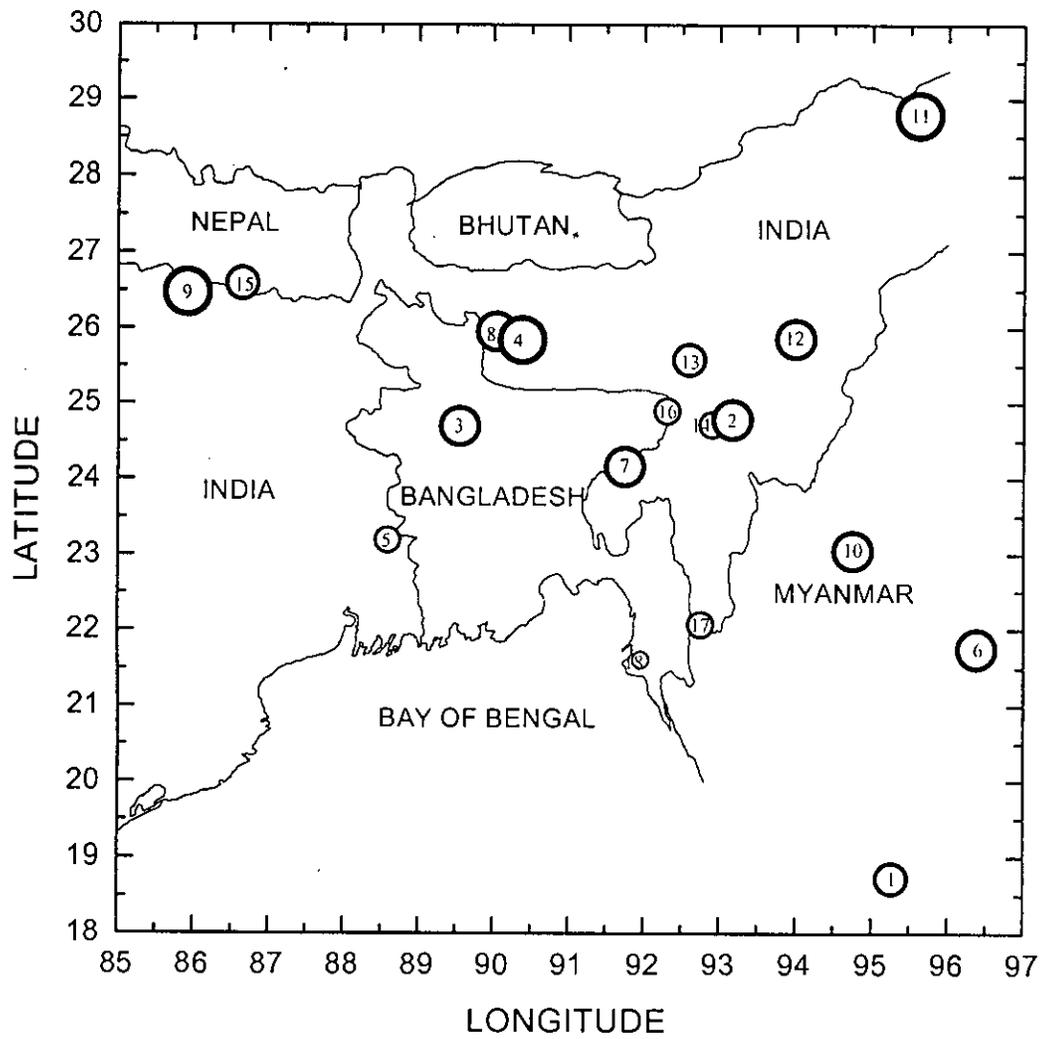


Figure 3.1. The region under consideration under consideration together with the earthquakes in this study

*Footnote: Number in figures refers to number in Table 3.1

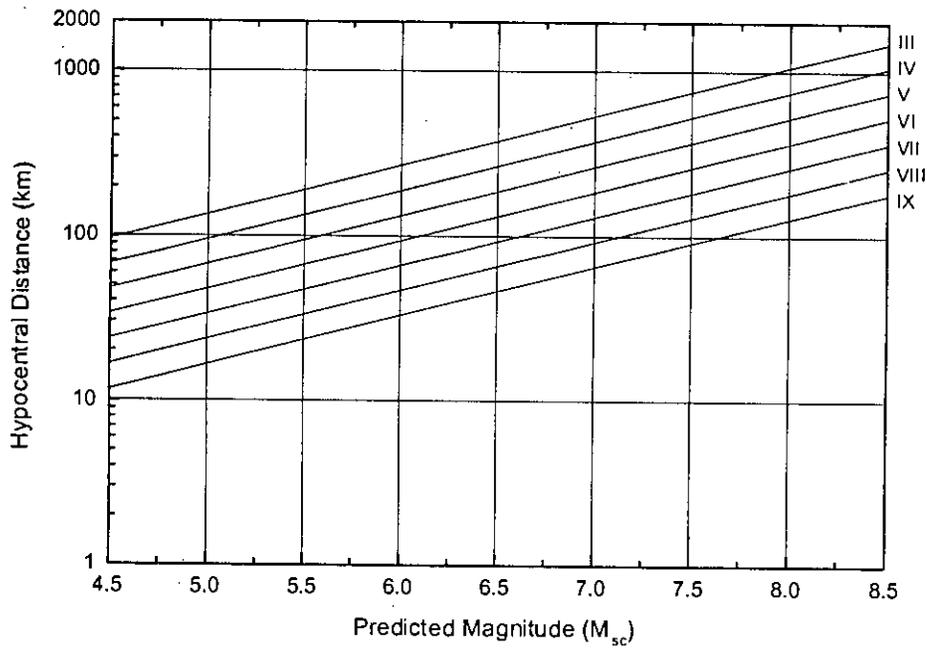


Figure 3.2. Magnitude-intensity relationships for whole data set, plotted for intensities $I = III-IX$

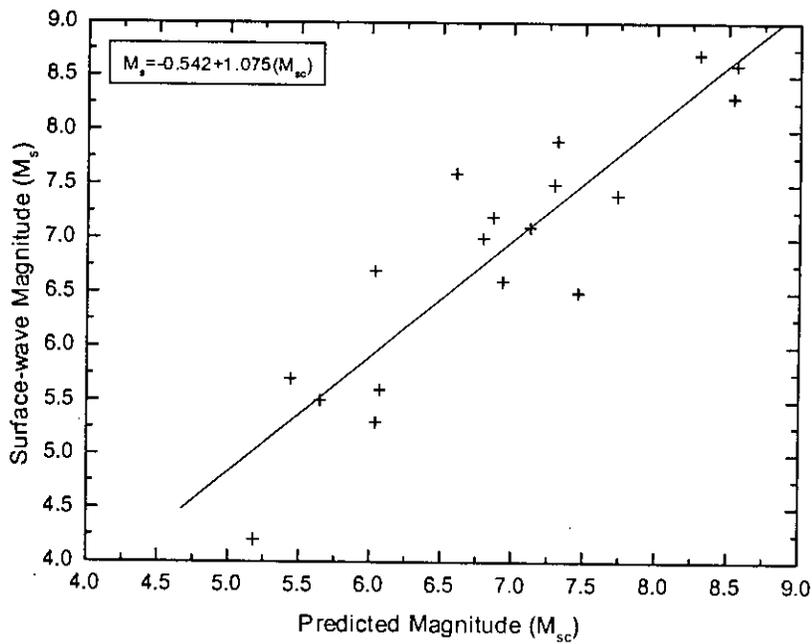


Figure 3.3. Surface-wave magnitudes M_s calculated from instrumental data versus macroseismic magnitudes M_{sc} predicted from the whole data set

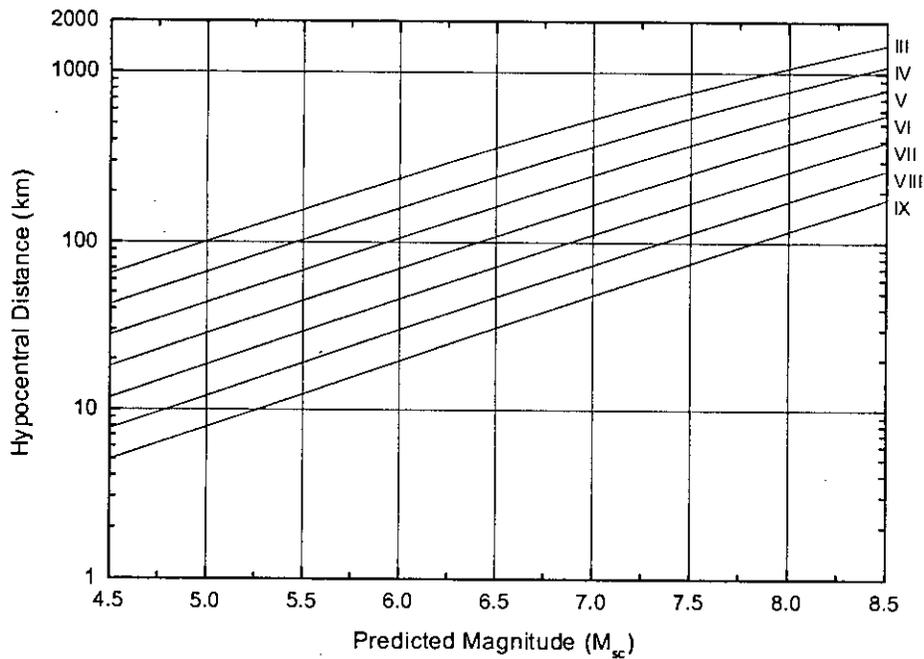


Figure 3.4. Magnitude-intensity relationships for NE-GB data, plotted for intensities $I = \text{III-IX}$

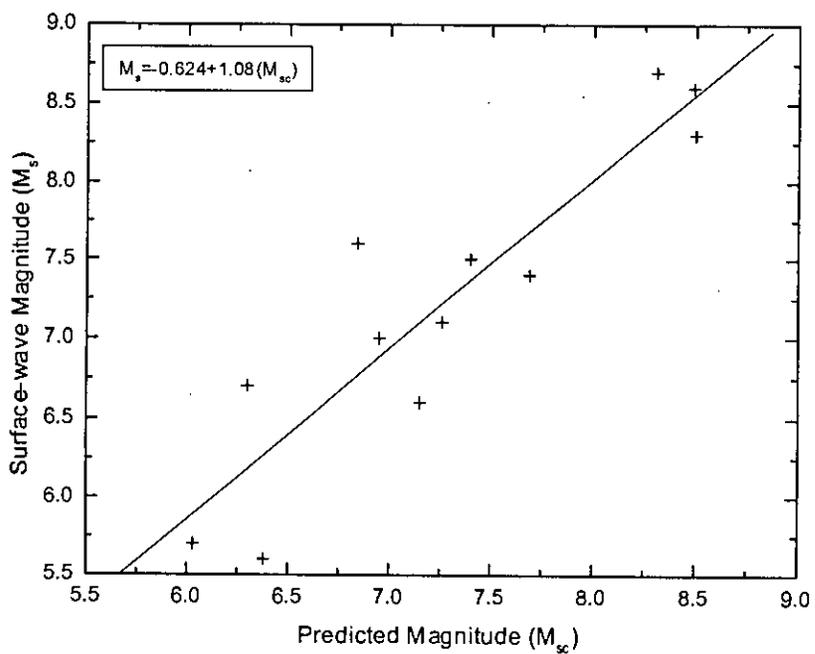


Figure 3.5. Surface-wave magnitudes M_s calculated from instrumental data versus macroseismic magnitudes M_{sc} predicted from the NE-GB data

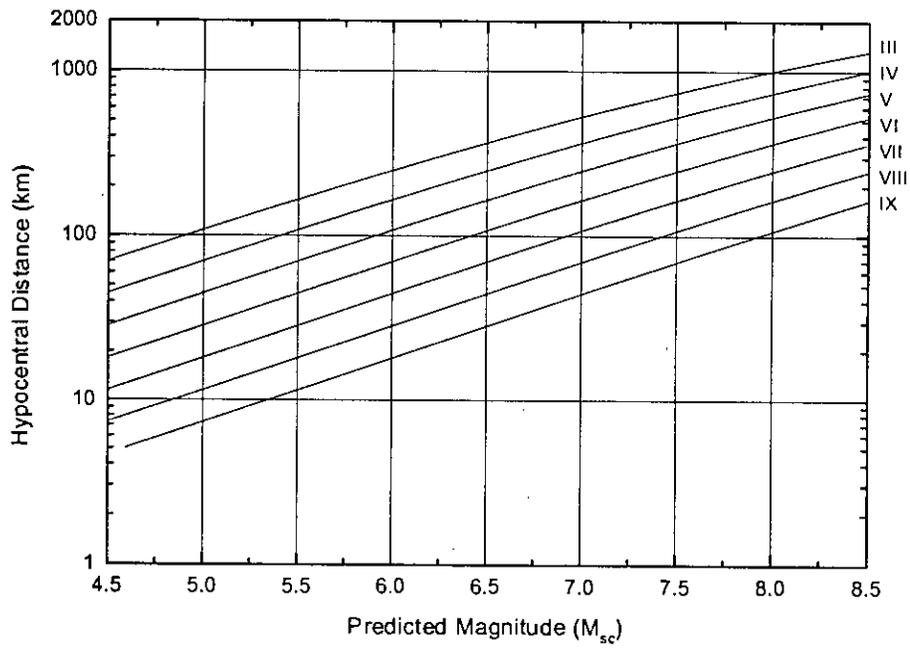


Figure 3.6. Magnitude-intensity relationships for NE data, plotted for intensities $I = \text{III-IX}$

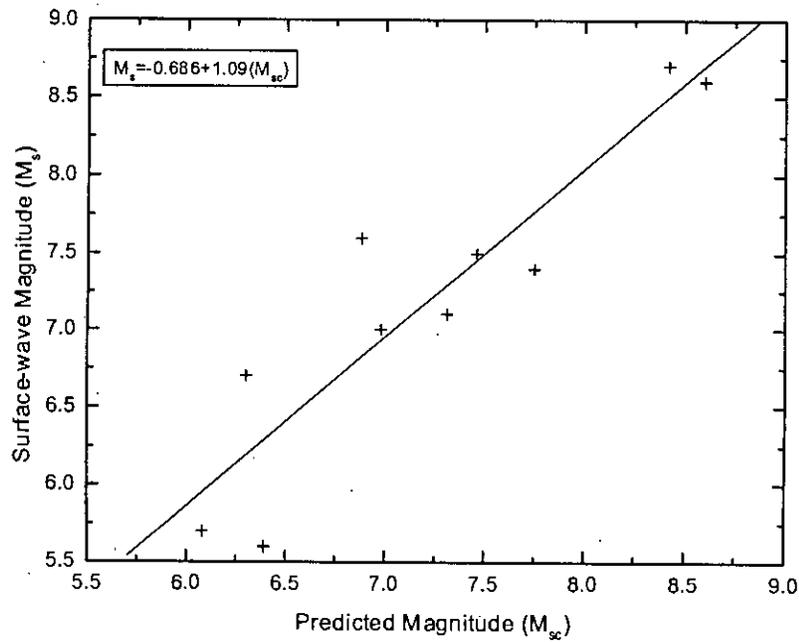


Figure 3.7. Surface-wave magnitudes M_s calculated from instrumental data versus macroseismic magnitudes M_{sc} predicted from the NE data

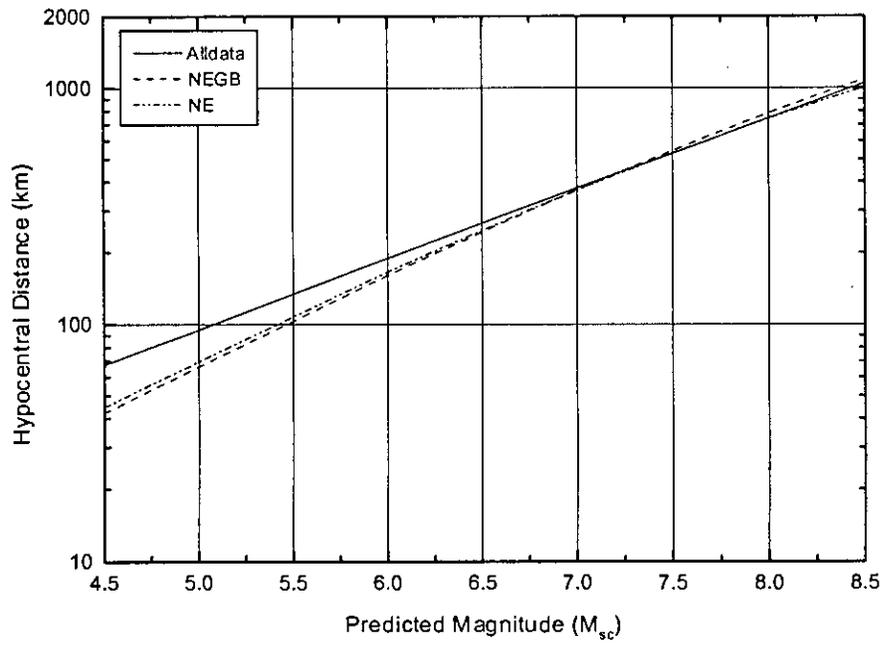


Figure 3.8 (a). Comparison of magnitude-intensity curves for the whole data set, NE-GB data and NE data for intensity $I = IV$

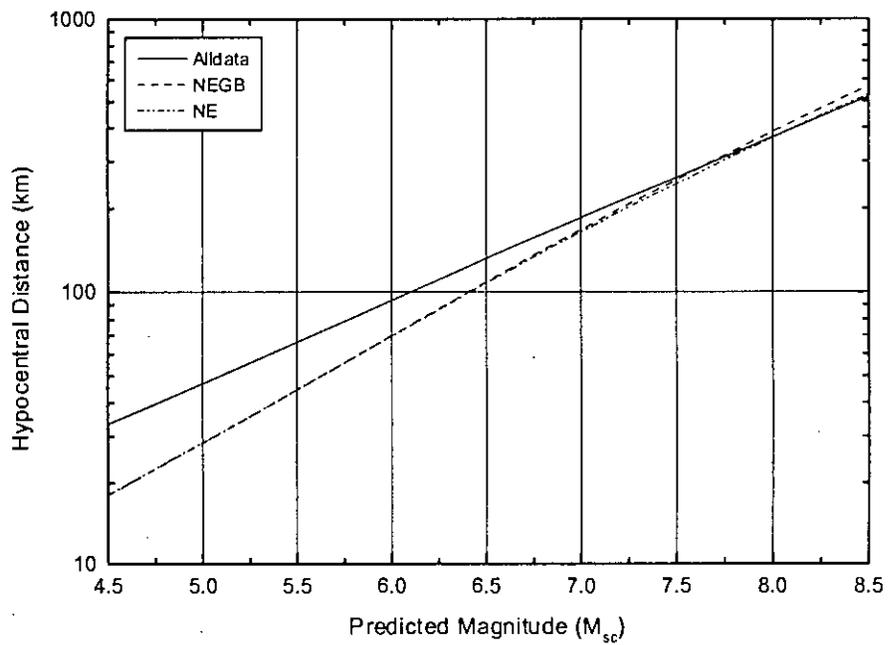


Figure 3.8 (b). Comparison of magnitude-intensity curves for the whole data set, NE-GB data and NE data for intensity $I = VI$

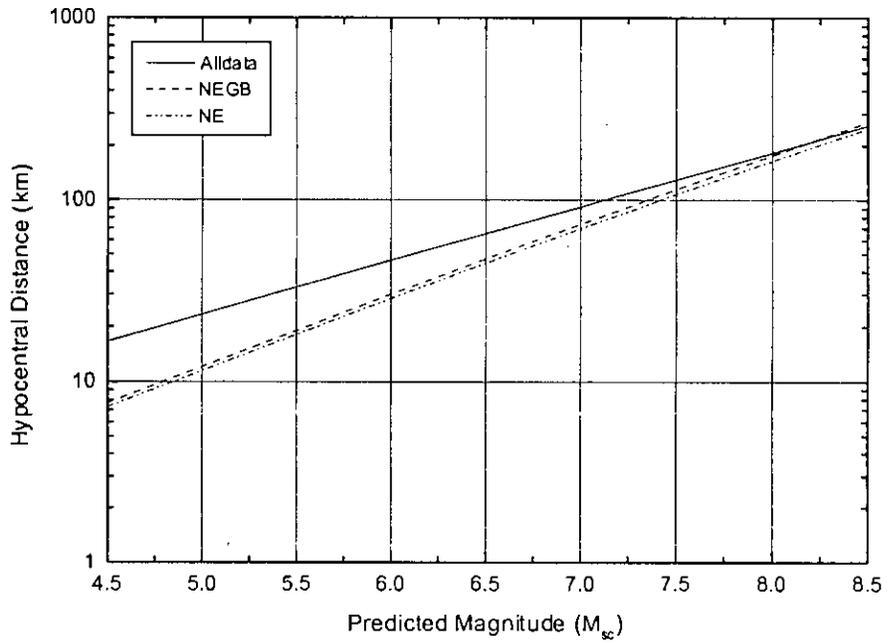


Figure 3.8 (c). Comparison of magnitude-intensity curves for the whole data set, NE-GB data and NE data for intensity $I = VIII$

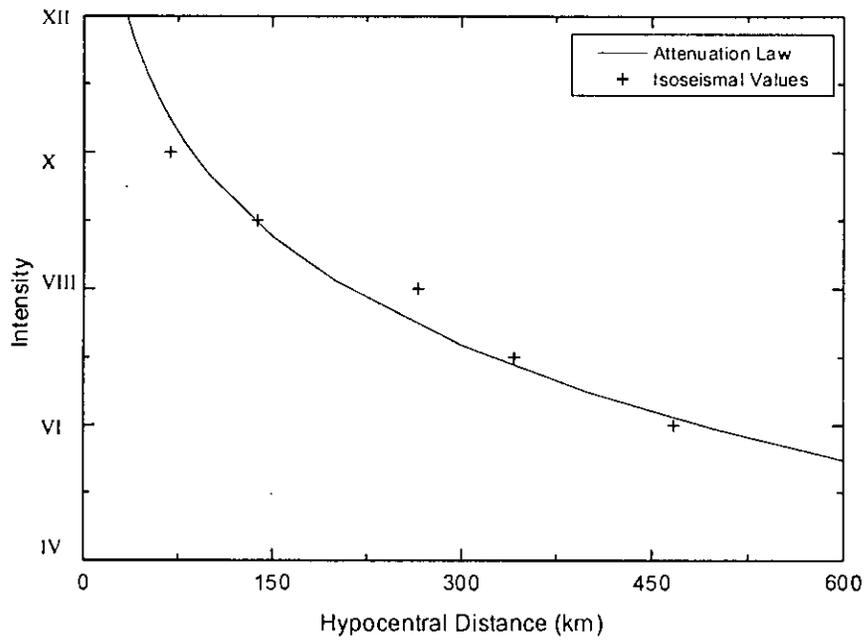


Figure 3.9 (a). Plot of isoseismal (I, D) data for 1897 Great Indian earthquake and mean intensity-attenuation curve for whole data set

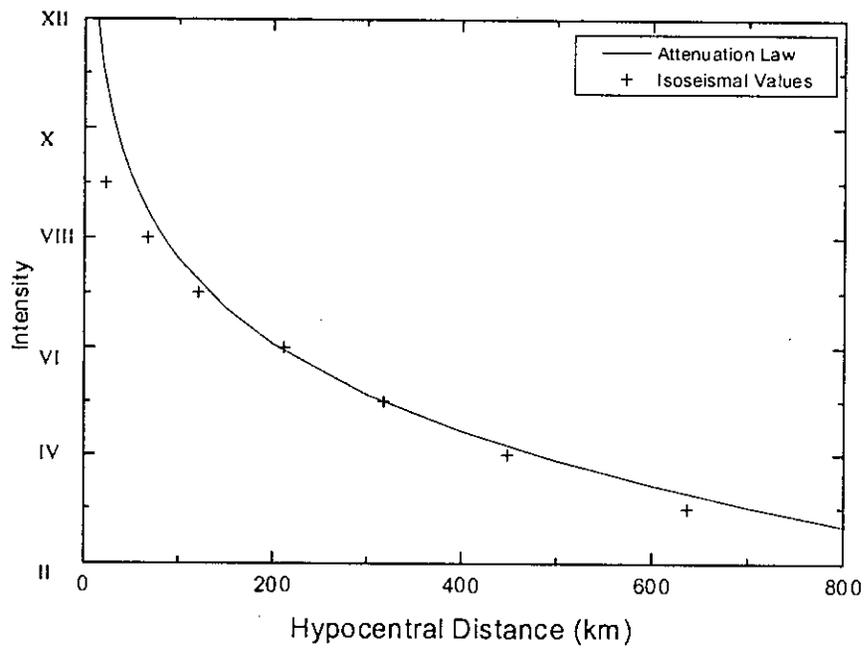


Figure 3.9 (b). Plot of isoseismal (I, D) data for 1930 Dhubri earthquake and mean intensity-attenuation curve for whole data set

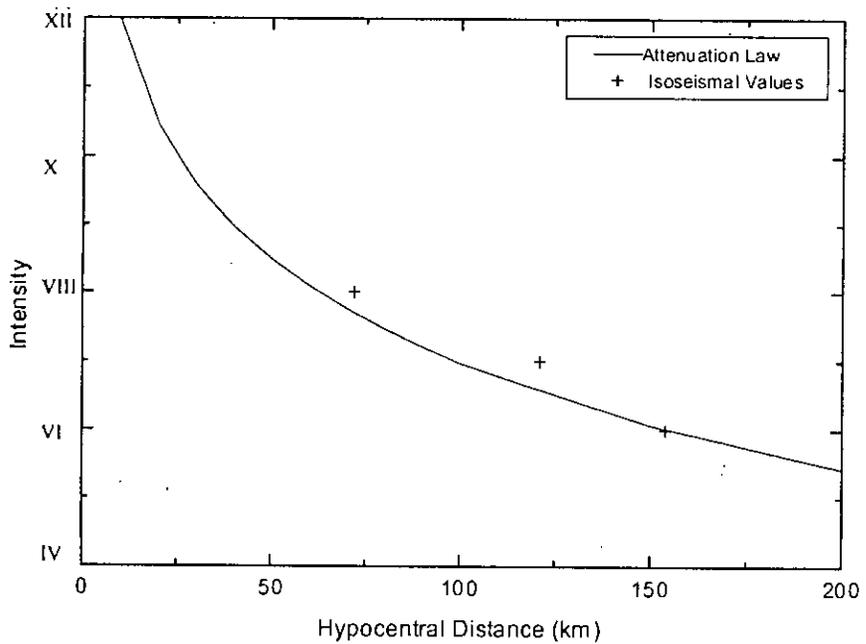


Figure 3.9 (c). Plot of isoseismal (I, D) data for 1988 Bihar-Nepal earthquake and mean intensity-attenuation curve for whole data set

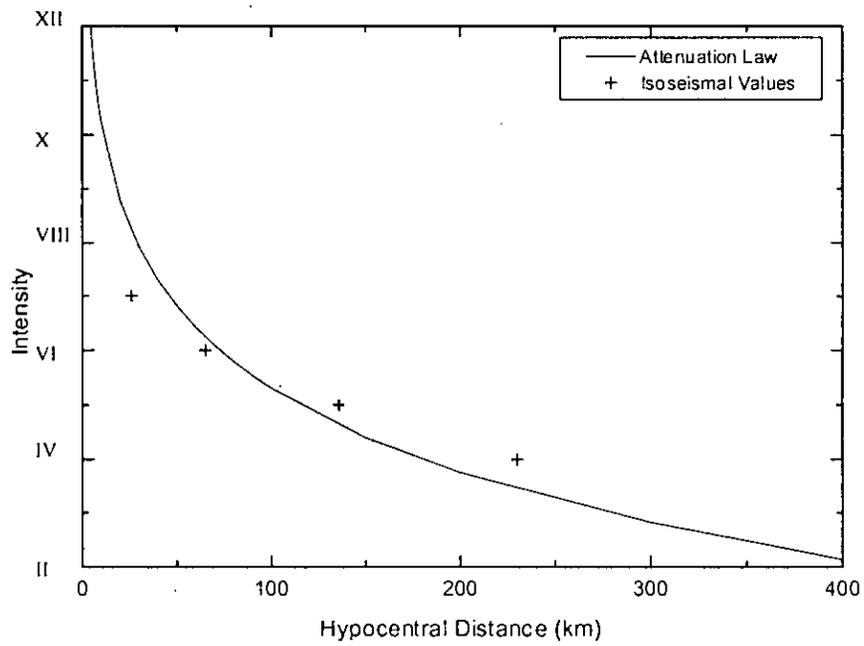


Figure 3.9 (d). Plot of isoseismal (I, D) data for 1997 Bangladesh-Myanmar earthquake and mean intensity-attenuation curve for whole data set

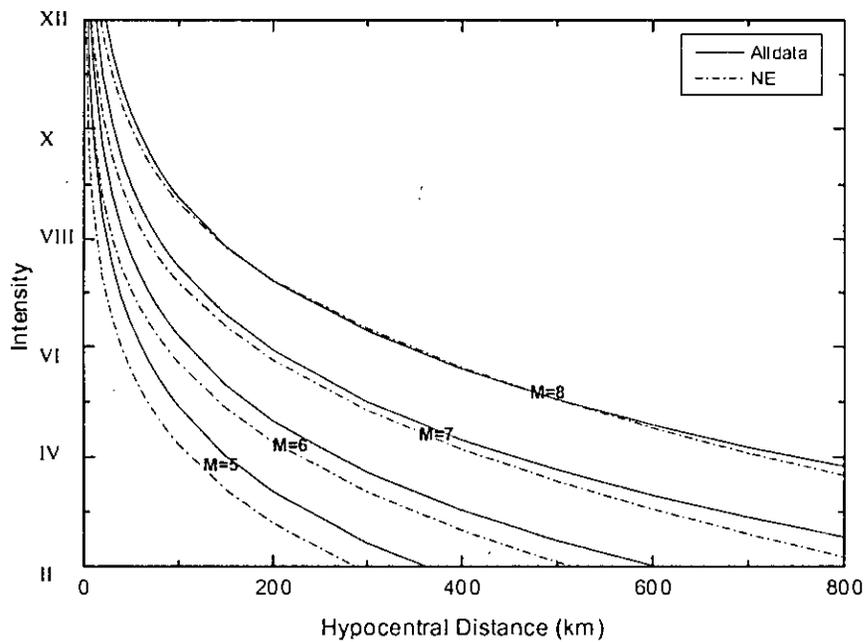


Figure 3.10. Comparison of mean intensity-attenuation curves for whole data set and NE, plotted for different surface-wave magnitudes

CHAPTER FOUR

CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUDING REMARKS

In the first part of this study intensity values of five large earthquakes having well documented macroseismic data are re-estimated using EMS scale. In the second part of the study magnitude-intensity and intensity-attenuation model for Bangladesh and its surrounding region (Bhutan, India, Nepal and Myanmar) have been developed based on 18 events.

Among the 18 events, isoseismal maps of 5 events namely 1869 Cachar earthquake, 1885 Bengal earthquake, 1897 Great Indian earthquake, 1918 Srimangal earthquake and 1930 Dhubri earthquake are completely revised here based on European Macroseismic Scale (EMS). Based on these revisions, epicenters of these 5 events are relocated. Also isoseismal maps of three recent events namely, 1997 Bangladesh-India, 1997 Bangladesh-Myanmar and 1999 Moheshkhali earthquakes are developed for the first time in this study. EMS intensities of the rest of the events are found using existing correlation of different intensity scales. Surface-wave magnitudes (M_s) of these 18 events vary between 4.2 to 8.7.

The advantage of using the derived equations is that epicentral intensities are not needed and the magnitude-intensity relationships may be used to assign magnitudes to earthquakes in regions of sparse population density. Although all the relationships derived in this work show a certain consistency with the data set, it is clear that more data are needed before a final conclusion about the intensity-attenuation rate in the study region can be drawn. The intensity-attenuation law developed here can help us to estimate hazard analysis at specified sites.

4.2 RECOMMENDATIONS

To understand clearly the earthquake occurrence phenomena in Bangladesh the following recommendations are made:

1. Intensity based seismic hazard map of Bangladesh and its surrounding should be developed. This will help us to assess the seismic risk of different areas of Bangladesh.
2. Reviewing and updating the building code of Bangladesh on the basis of above studies.
3. Study of regional tectonics with particular emphasis to locate active faults. There are many deep-seated faults in the basement complex. Their length, position and their relation with the regional tectonics should be studied in details.
4. The focal mechanisms of earthquake occurrence in Bangladesh should be studied to determine the fault parameters and depth of hypocentre.
5. Installation of seismic observatories and instrumentation of selected new structures to acquire strong motion data.
6. Development of simple guidelines regarding seismic loading for non-engineered constructions (in local language) and arranging for wide dissemination with the help of NGOs.

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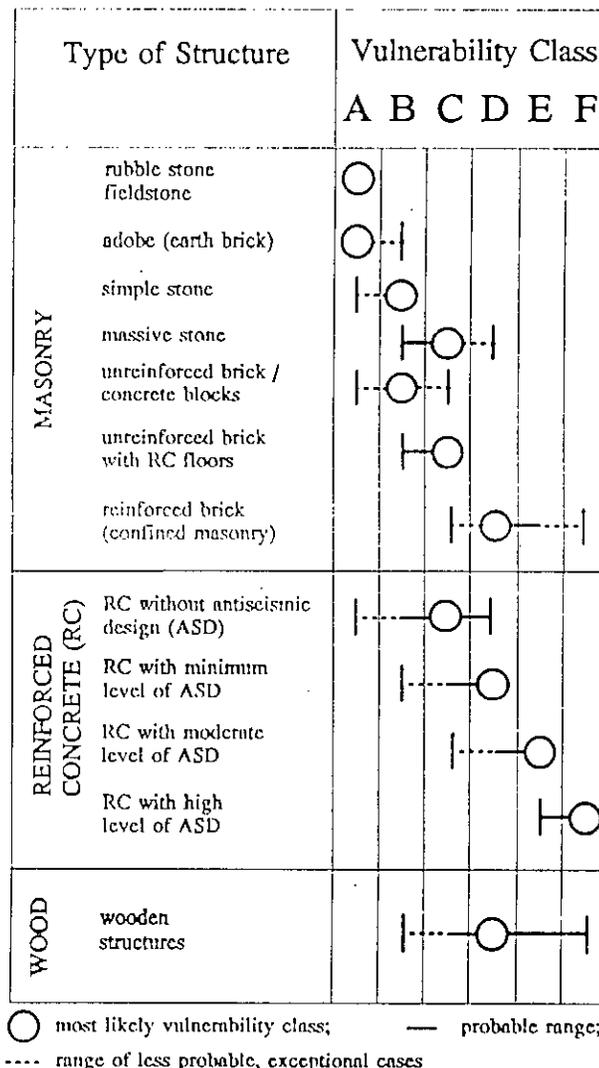
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APPENDIX-A
EUROPEAN MACROSEISMIC SCALE

3 MACROSEISMIC INTENSITY SCALE

3.1 Classifications used in the EMS

3.1.1 Differentiation of structures (buildings) into vulnerability classes



3.1.2 Definition of quantity

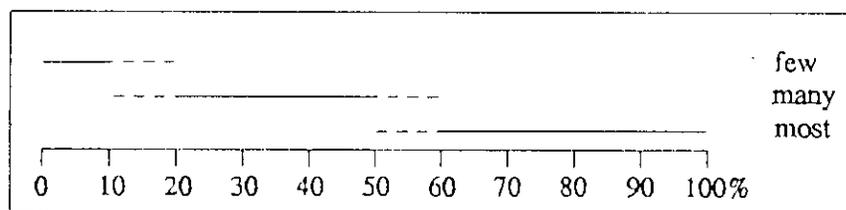
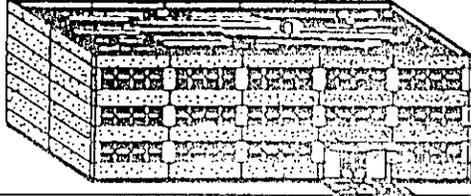
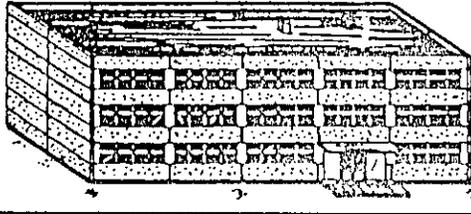
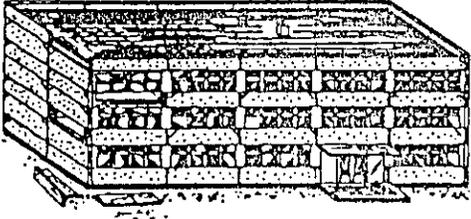
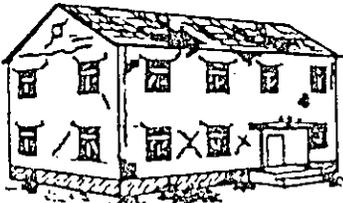
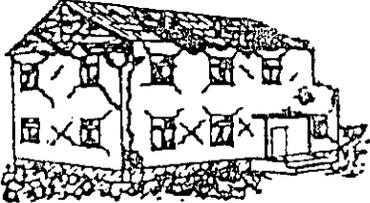
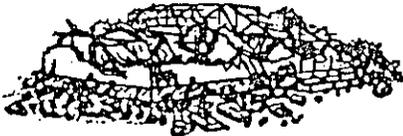


Table 3: Classification of damage to buildings of reinforced concrete

	<p>Grade 1: Negligible to slight damage (no structural damage) fine cracks in plaster over frame members and in partitions.</p>
	<p>Grade 2: Moderate damage (slight structural damage, moderate non-structural damage) hair-line cracks in columns and beams; mortar falls from the joints of suspended wall panels; cracks in partition walls; fall of pieces of brittle cladding and plaster.</p>
	<p>Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage) cracks in columns with detachment of pieces of concrete, cracks in beams.</p>
	<p>Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage). severe damage to the joints of the building skeleton with destruction of concrete and protrusion of reinforcing rods; partial collapse; tilting of columns.</p>
	<p>Grade 5: Destruction (very heavy structural damage) total or near total collapse.</p>

3.1.3 Classification of damage

Note: the way in which a building deforms under earthquake loading depends on the building type. As a broad categorisation one can group together masonry buildings and buildings of reinforced concrete.

Table 2: Classification of damage to masonry buildings	
	<p>Grade 1: Negligible to slight damage (no structural damage) hair-line cracks in very few walls; fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases only.</p>
	<p>Grade 2: Moderate damage (slight structural damage, moderate non-structural damage) cracks in many walls; fall of fairly large pieces of plaster; parts of chimneys fall down.</p>
	<p>Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage) large and extensive cracks in most walls; pantiles or slates slip off. Chimneys are broken at the roof line; failure of individual non-structural elements.</p>
	<p>Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage). serious failure of walls; partial structural failure.</p>
	<p>Grade 5: Destruction (very heavy structural damage) total or near total collapse.</p>

3.2 Definitions of intensity degrees

Arrangement of the scale:

- a) Effects on humans
- b) Effects on objects and on nature
(excluding damage to buildings, effects on ground and ground failure)
- c) Damage to buildings

Introductory remark:

The single intensity degrees can include the effects of shaking of the respective lower intensity degree(s), also when these effects are not mentioned explicitly.

I. Not felt

- a) Not felt even under the most favourable circumstances.
- b) No effect.
- c) No damage.

II. Scarcely felt

- a) The tremor is felt only by a very few (less than 1%) individuals at rest and in a specially receptive position indoors.
- b) No effect.
- c) No damage.

III. Weak

- a) The earthquake is felt indoors by a few. People at rest feel a swaying or light trembling.
- b) Hanging objects swing slightly.
- c) No damage.

IV. Largely observed

- a) The earthquake is felt indoors by many and felt outdoors only by very few. A few people are awakened. The level of vibration is not frightening. The vibration is moderate. Observers feel a slight trembling or swaying of the building, room or bed, chair etc.
- b) China, glasses, windows and doors rattle. Hanging objects swing. Light furniture shakes visibly in a few cases. Woodwork creaks in a few cases.
- c) No damage.

V. Strong

- a) The earthquake is felt indoors by most, outdoors by few. A few people are frightened and run outdoors. Many sleeping people awake. Observers feel a strong shaking or rocking of the whole building, room or furniture.
- b) Hanging objects swing considerably. China and glasses clatter together. Small, top-heavy and/or precariously supported objects may be shifted or fall down. Doors and windows swing open or shut. In a few cases window panes break. Liquids oscillate and may spill from well-filled containers. Animals indoors may become uneasy.
- c) Damage of grade 1 to a few buildings.

VI. Slightly damaging

- a) Felt by most indoors and by many outdoors. A few persons lose their balance. Many people are frightened and run outdoors.
- b) Small objects of ordinary stability may fall and furniture may be shifted. In few instances dishes and glassware may break. Farm animals (even outdoors) may be frightened.
- c) Damage of grade 1 is sustained by many buildings; a few suffer damage of grade 2.

VII. Damaging

- a) Most people are frightened and try to run outdoors. Many find it difficult to stand, especially on upper floors.
- b) Furniture is shifted and top-heavy furniture may be overturned. Objects fall from shelves in large numbers. Water splashes from containers, tanks and pools.
- c) Many buildings of vulnerability class B and a few of class C suffer damage of grade 2. Many buildings of class A and a few of class B suffer damage of grade 3; a few buildings of class A suffer damage of grade 4. Damage is particularly noticeable in the upper parts of buildings.

VIII. Heavily damaging

- a) Many people find it difficult to stand, even outdoors.
- b) Furniture may be overturned. Objects like TV sets, typewriters etc. fall to the ground. Tombstones may occasionally be displaced, twisted or overturned. Waves may be seen on very soft ground.
- c) Many buildings of vulnerability class C suffer damage of grade 2. Many buildings of class B and a few of class C suffer damage of grade 3. Many buildings of class A and a few of class B suffer damage of grade 4; a few buildings of class A suffer damage of grade 5. *A few buildings of class D suffer damage of grade 2.*

IX. Destructive

- a) General panic. People may be forcibly thrown to the ground.
- b) Many monuments and columns fall or are twisted. Waves are seen on soft ground.
- c) Many buildings of vulnerability class C suffer damage of grade 3. Many buildings of class B and a few of class C suffer damage of grade 4. Many buildings of class A and a few of class B suffer damage of grade 5.
Many buildings of class D suffer damage of grade 2; a few suffer grade 3. A few buildings of class E suffer damage of grade 2.

X. Very destructive

- c) Many buildings of vulnerability class C suffer damage of grade 4. Many buildings of class B and a few of class C suffer damage of grade 5, as do most buildings of class A.
Many buildings of class D suffer damage of grade 3; a few suffer grade 4. Many buildings of class E suffer damage of grade 2; a few suffer grade 3. A few buildings of class F suffer damage of grade 2.

XI. Devastating

- c) Most buildings of vulnerability class C suffer damage of grade 4. Most buildings of class B and many of class C suffer damage of grade 5.
Many buildings of class D suffer damage of grade 4; a few suffer grade 5. Many buildings of class E suffer damage of grade 3; a few suffer grade 4. Many buildings of class F suffer damage of grade 2, a few suffer grade 3.

XII. Completely devastating

- c) Practically all structures above and below ground are destroyed.

APPENDIX-B
INTENSITY SCALES AND CORRELATIONS

Table A4
Oldham Scale of Intensity

I.	The first isoseist includes all places where the destruction of brick and stone buildings was practically universal.
II.	The second, those places where damage to masonry or brick buildings was universal, often serious, amounting in some cases to destruction.
III.	The third, those places where the earthquake was violent enough to damage all or nearly all brick buildings.
IV.	The fourth, those places where the earthquake was universally felt, severe enough to disturb furniture and loose objects, but not severe enough to cause damage, except in a few instances, to brick buildings.
VI.	The fifth, those places where the earthquake was smart enough to be generally noticed, but not severe enough to cause any damage.
VII.	The sixth, all those places where the earthquake was only noticed by a small proportion of people who happened to be sensitive, and being seated or lying down were favorably situated for observing it.

The Rossi-Forel Scale

The most commonly used form of the Rossi-Forel (R.F.) scale reads as follows:

- I. Microseismic shock. Recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds: the shock felt by an experienced observer.
- II. Extremely feeble shock. Recorded by several seismographs of different kinds; felt by a small number of persons at rest.
- III. Very feeble shock. Felt by several persons at rest; strong enough for the direction or duration to be appreciable.
- IV. Feeble shock. Felt by persons in motion; disturbance of movable objects, doors, windows, cracking of ceilings.
- V. Shock of moderate intensity. Felt generally by everyone; disturbance of furniture, beds, etc., ringing of some bells.
- VI. Fairly strong shock. General awakening of those asleep; general ringing of bells; oscillation of chandeliers; stopping of clocks; visible agitation of trees and shrubs; some startled persons leaving their dwellings.
- VII. Strong shock. Overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.
- VIII. Very strong shock. Fall of chimneys; cracks in the walls of buildings.
- IX. Extremely strong shock. Partial or total destruction of some buildings.
- X. Shock of extreme intensity. Great disaster; ruins; disturbance of the strata, fissures in the ground, rock falls from mountains.

(Taken from Elementary Seismology by Charles F. Richter)

The Modified Mercalli Intensity Scale

Mercalli's (1902) improved intensity scale served as a basis for the scale advanced by Wood and Neumann (1931), known as the modified Mercalli scale and commonly abbreviated MM. The modified version is described below with some improvements by Richter (1958). The following remarks are taken almost verbatim from Elementary Seismology, Charles F. Richter (W. H. Freeman and Company, San Francisco, copyright C 1958).

To eliminate many verbal repetitions in the original scale, the following convention has been adopted. Each effect is named at that level of intensity at which it first appears frequently and characteristically. Each effect may be found less strongly, or in fewer instances, at the next lower grade of intensity; more strongly or more often at the next higher grade. A few effects are named at two successive levels to indicate a more gradual increase.

Masonry A, B, C, D. To avoid ambiguity of language, the quality of masonry, brick or otherwise, is specified by the following lettering (which has no connection with the conventional Class A, B, C construction).

Masonry A. Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.

Masonry B. Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.

Masonry C. Ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at corners, but neither reinforced nor designed against horizontal forces.

Masonry D. Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

Modified Mercalli Intensity Scale of 1931 (Abridged and Rewritten by C. F. Richter.)

1. Not felt. Marginal and long-period of large earthquakes.
2. Felt by persons at rest, on upper floors, or favorably placed.
3. Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.
4. Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of 4, wooden walls and frames crack.

5. Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.
6. Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, and so on, off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Trees, bushes shaken visibly, or heard to rustle.
7. Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices, unbraced parapets, and architectural ornaments. Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.
8. Steering of motor cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.
9. General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. General damage to foundations. Frame structures, if not bolted, shifted off foundations. Frames racked. Conspicuous cracks in ground. In alluviated areas sand and mud ejected, earthquake fountains, sand craters.
10. Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.
11. Rails bent greatly. Underground pipelines completely out of service.
12. Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

Intensity (grade)	Effects
1	Only recorded by Seismographs.
2	Only felt by individual people at rest.
3	Only felt by a few people.
4	Felt by many people. Dishes and doors rattle.
5	Hanging objects swing, many sleeping people awoken.
6	Slight damage in buildings and small cracks in plaster.
7	Cracks in plaster, gaps in walls and chimneys.
8	Wide gaps in masonry, parts of gables and cornices fall down.
9	In some buildings walls and roofs collapse, landslips.
10	Collapse of many buildings, cracks in ground up to widths of 1 m.
11	Many cracks in ground, landslips and falls of rocks.
12	Strong changes in the surface of the ground.

I (grade)	a (cm sec ⁻²)	v (cm sec ⁻¹)	x ₀ (mm)
5	12-25	1.0- 2.0	0.5- 1.0
6	25-50	2.1- 4.0	1.1- 2.0
7	50-100	4.1- 8.0	2.1- 4.0
8	100-200	8.1-16.0	4.1- 8.0
9	200-400	16.1-32.0	8.1-16.0
10	400-800	32.1-64.0	16.1-32.0

I = Intensity of earthquakes

a = Ground acceleration in cm sec⁻² for periods between 0.1 sec and 0.5 sec.

v = Velocity of ground oscillation in cm sec⁻¹ for periods between 0.5 sec and 2.0 sec.

x₀ = Amplitude of movement of centre of gravity of the pendulum mass in mm. The natural period of the pendulum is 0.25 sec, the logarithmic decrement is 0.5.

Brief description of the Russian (Geofian) intensity scale with ground motions assigned by Medvedev, Sponheuer, and Karnik (1964) (from Barosh¹)

MM	RF
I	I
II	I-II
III	III
IV	IV-V
V	V-VI
VI	VI-VII
VII	VIII
VIII	VIII+ to IX-
IX	IX+
X-XII	X

APPENDIX-C3

Conversion of Oldham scale intensity to Rossi-Forel (R.F.) scale intensity to equivalent Modified Mercalli (MM) scale intensity

Oldham scale	Equivalent R.F. scale	Equivalent M.M. scale
1	X	X to XII
2	IX	IX (-)
3	VIII	VII (+) to VIII (-)
4	VI & VII	VI
5	IV & V	IV
6	II & III	II (+) to III

PREDICTING EFFECTS OF SEISMIC DISTURBANCES

UNITED STATES
Modified
Mercalli
(Wood and
Neumann, 1931)

RUSSIA
GEOFIAN
(Medvedev,
1953)

JAPAN
Japanese
(Kawasumi,
1951)

I	I	0
	II	I
II	III	
III		
IV	IV	II
V	V	III
VI	VI	IV
VII	VII	V
VIII	VIII	
IX	IX	VI
X	X	
XI	XI	VII
XII	XII	

Comparison of U. S., Russian, and Japanese
intensity scales (from Barosh¹)

APPENDIX-C
PHOTOGRAPHS OF 5 REESTIMATED EARTHQUAKES
(1869 Cachar, 1885 Bengal, 1897 Great Indian, 1918 Srimangal and
1930 Dhubri earthquakes)

**PHOTOGRAPHS AND FIGURES OF 1869 CACHAR
EARTHQUAKE**



Fig. 1. Scene in Bazaar.

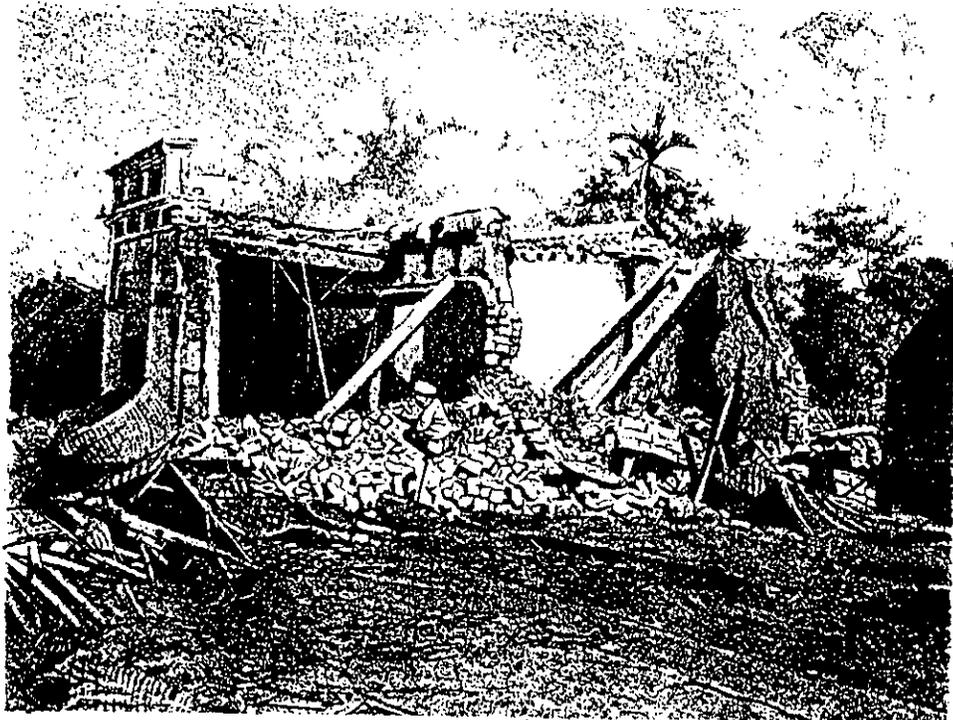


Fig. 2. House in Bazaar.



Fig. 1 on Bazaar road.



Fig. 2. Scene in Bazaar.



Fig. 3. Inside of Church.

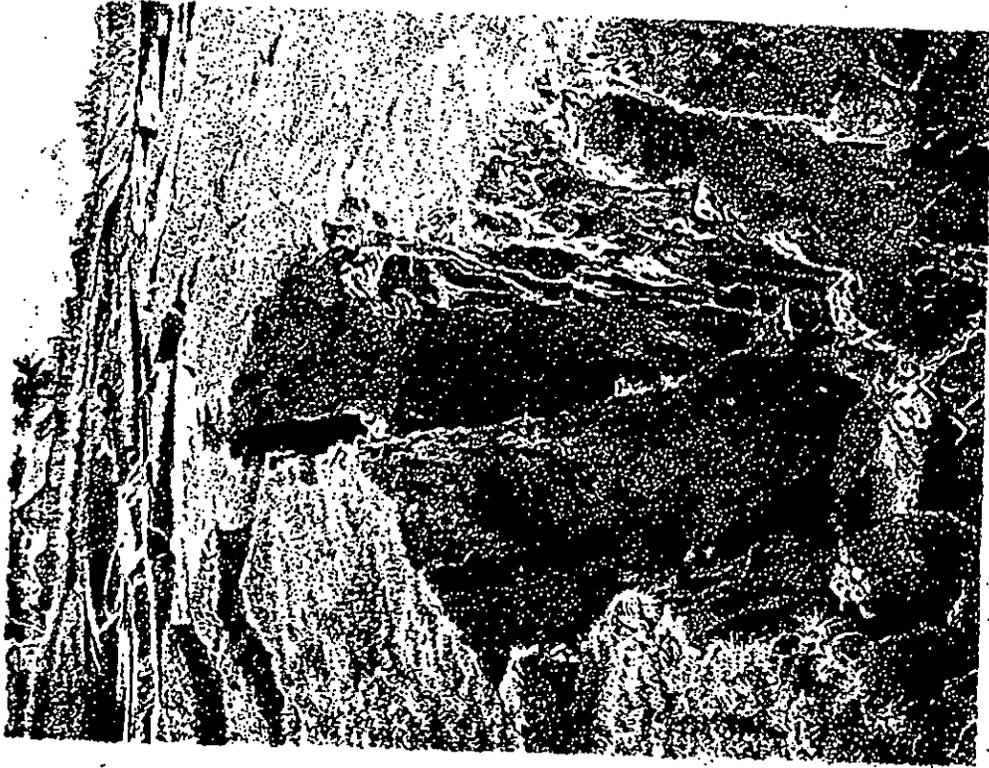


Fig. 1. Earthbed left near river.



Fig. 2. Slipped banks of river.



Fig. 3. Fissured ground on banks of river.

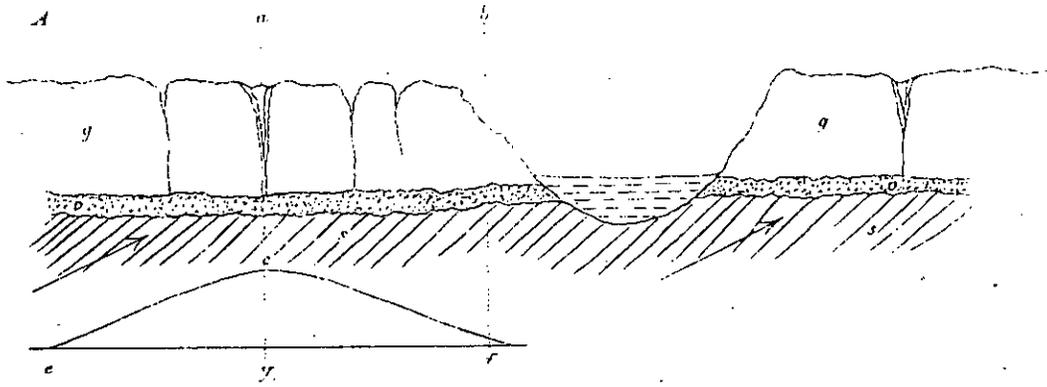


Fig. 1. Diagram to illustrate the formation of Earth fissure

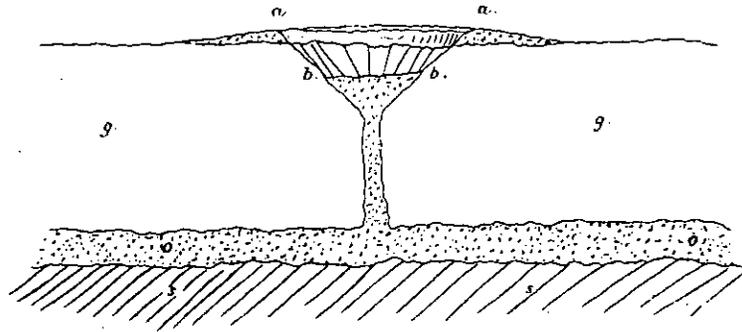
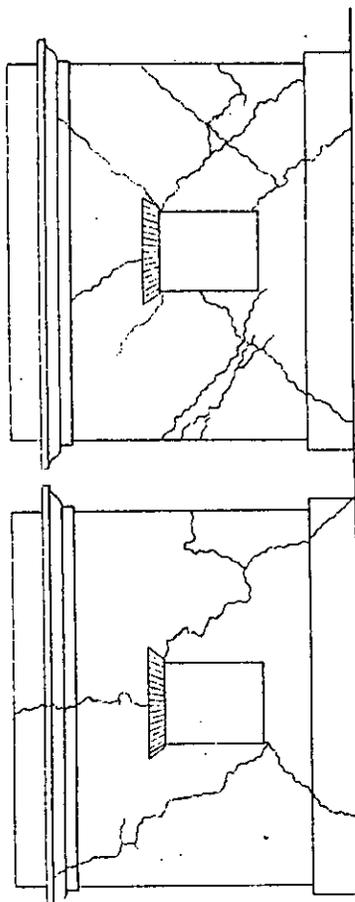
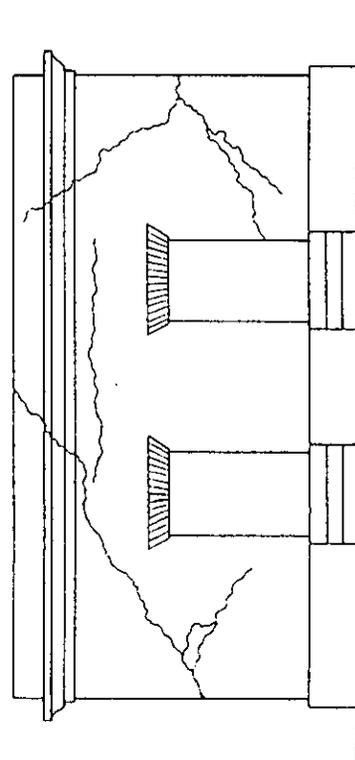


Fig. 2. Diagrammatic section of a sand crater.



East Elevation.

West Elevation.



South Elevation.

POLICE GUARD - SILCHAR

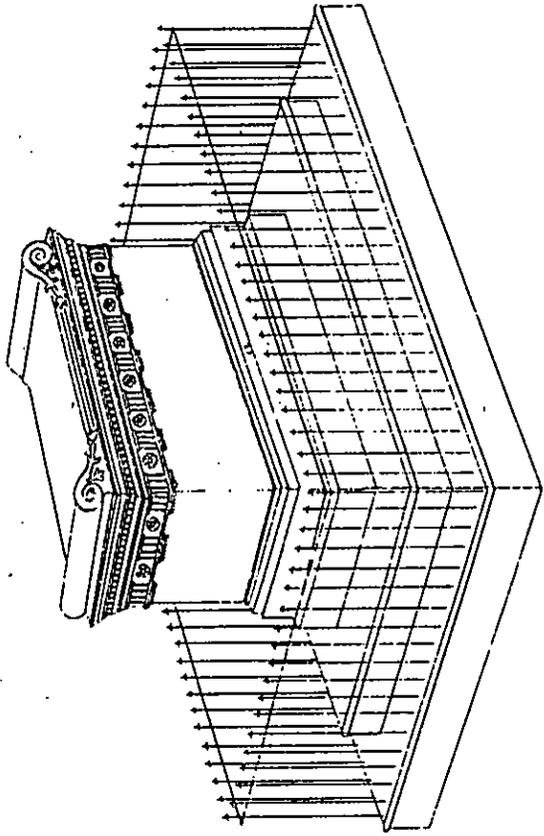


Fig. 1 Perspective Elevation of Mc Stewart's Tomb

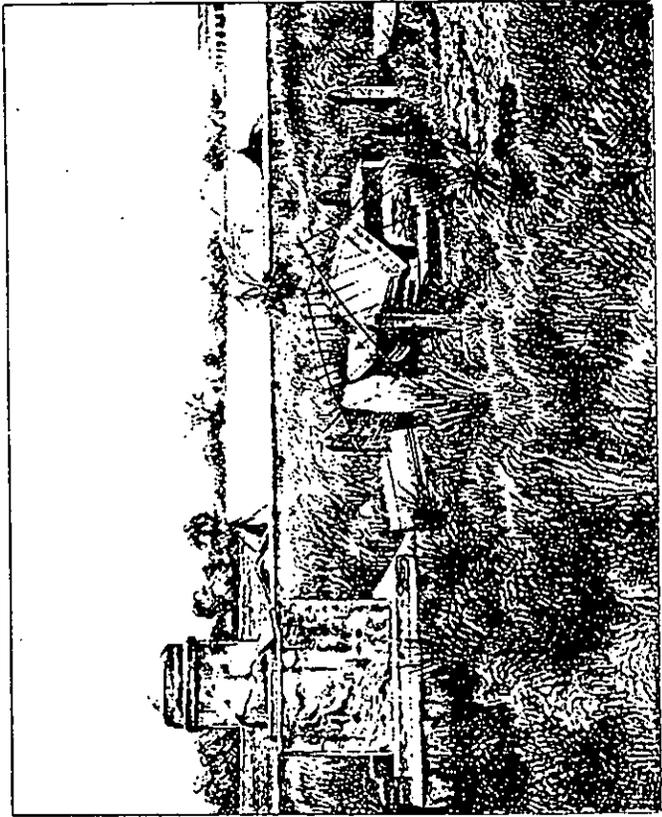


Fig. 2 The grave overthrown by the earthquake

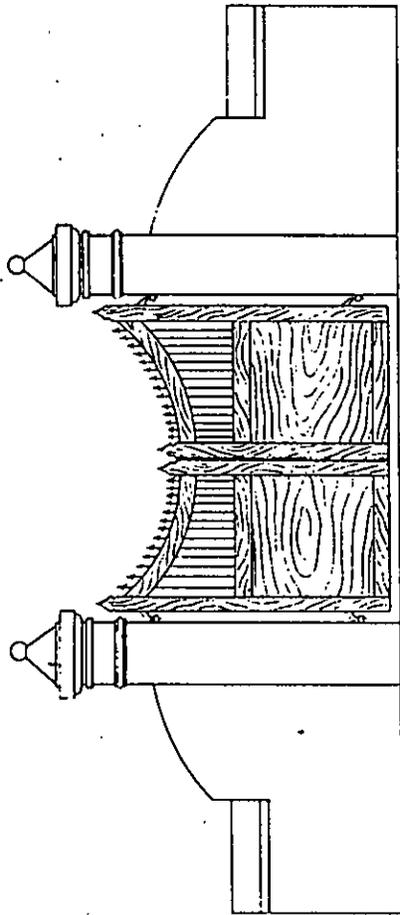


Fig. 1 Elevation of Cemetery Gate Silchar.

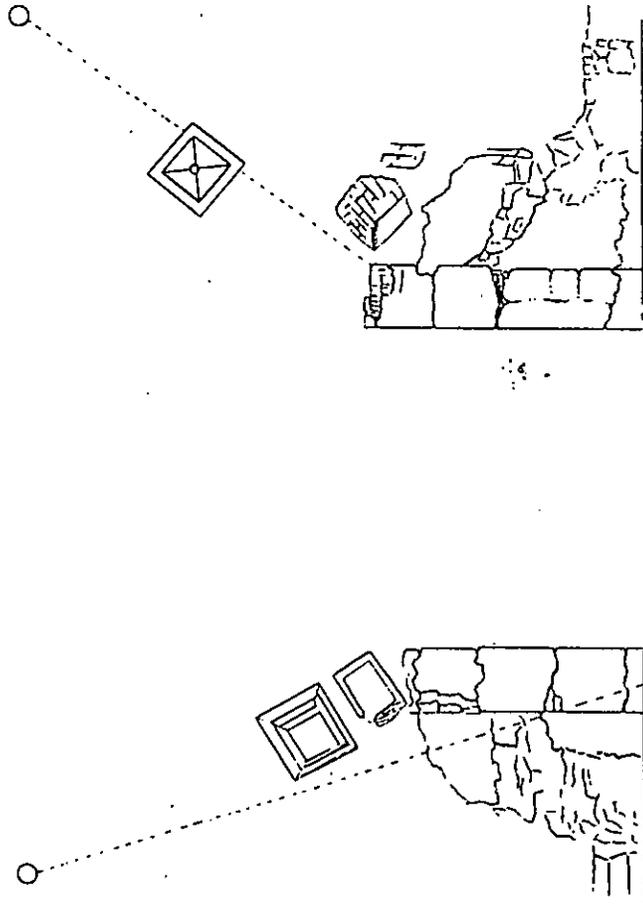


Fig. 2 Sketch Plan of overturned Cemetery gate pillars Silchar



Fig. 1. Side view of Church.

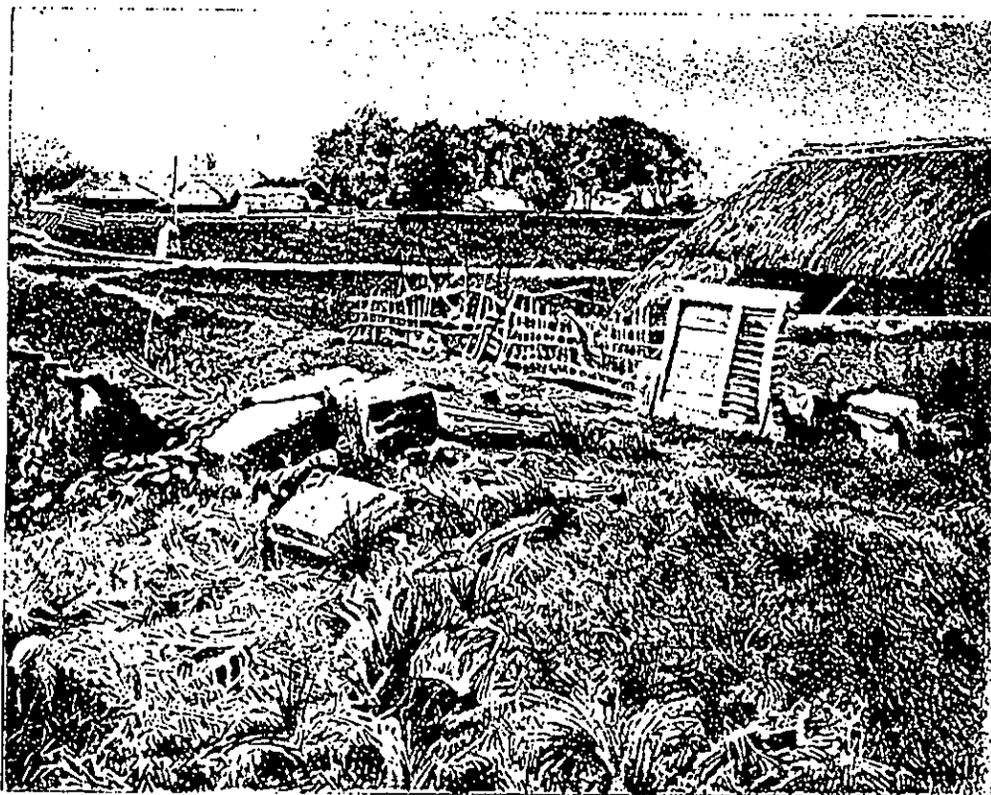
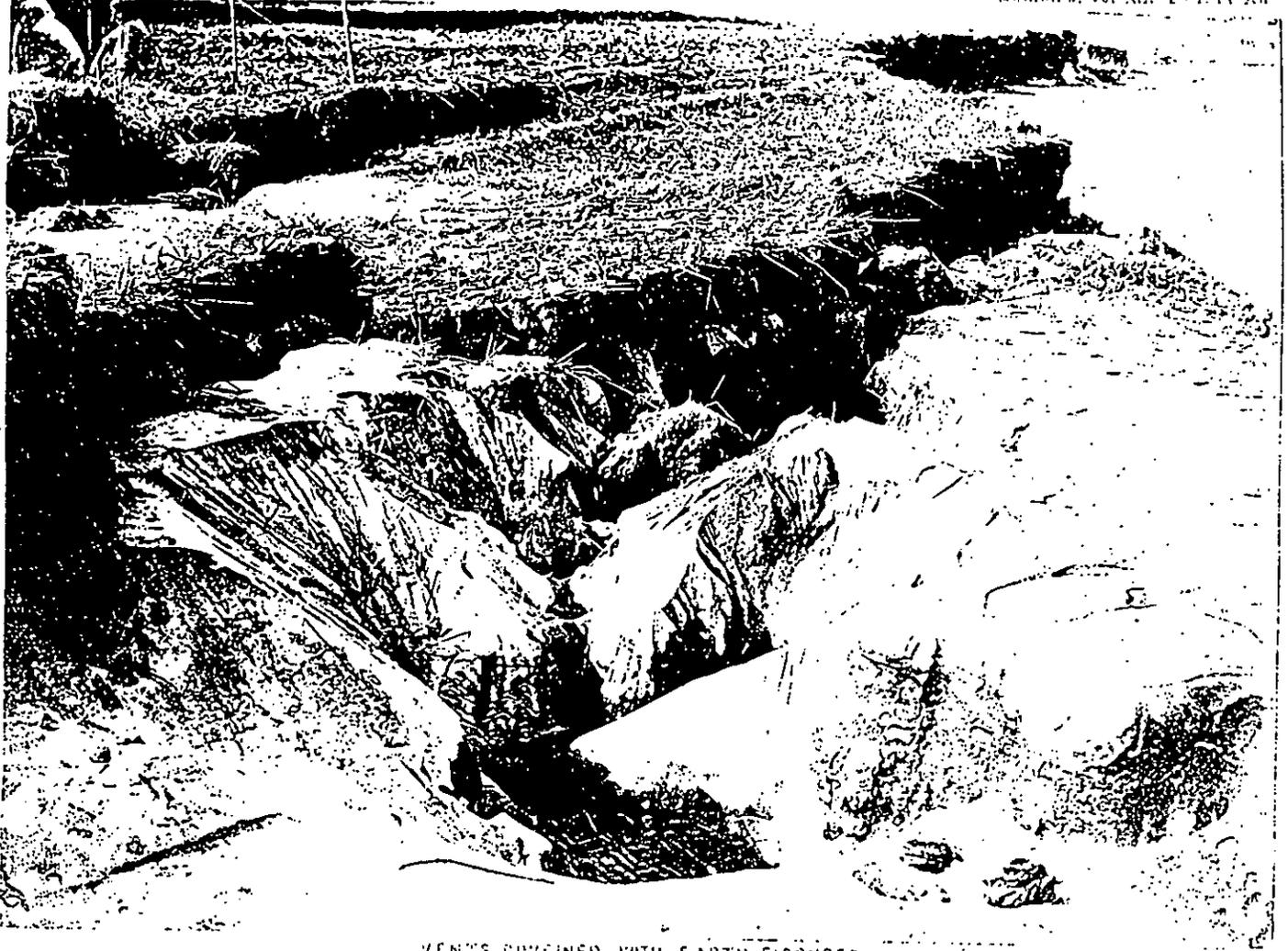


Fig. 2. Gateway of Cemetery.



VENTS COVERED WITH EARTH FISSURES.

**PHOTOGRAPHS AND FIGURES OF 1885 BENGAL
EARTHQUAKE**

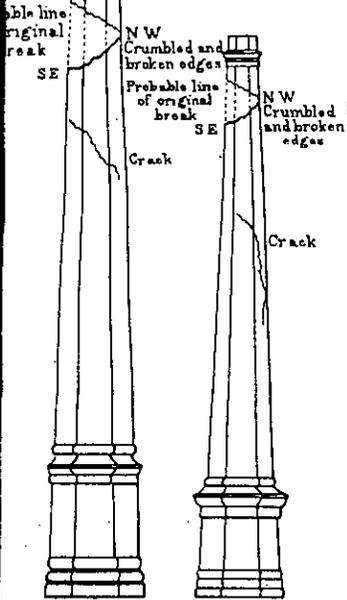
SERAJGANJ JUTE COMPANY'S WORKS.

Mill Chimney Hk 135 ft

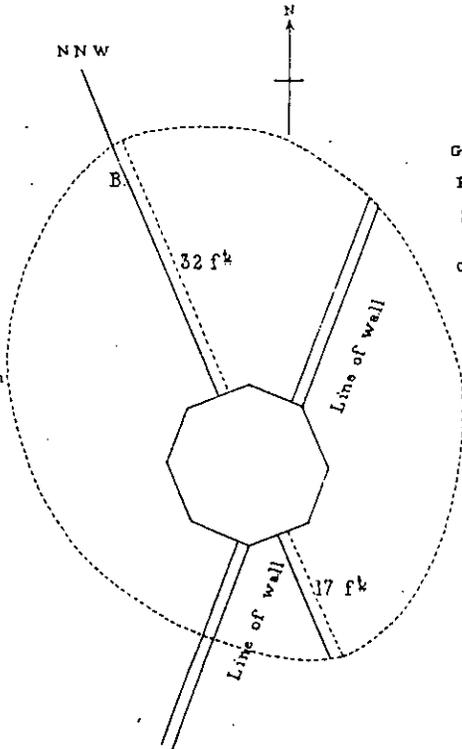
ELEVATION

Fig. 1.

Factory Chimney Hk 95 ft



Scale 1/4 Inch = 12 ft

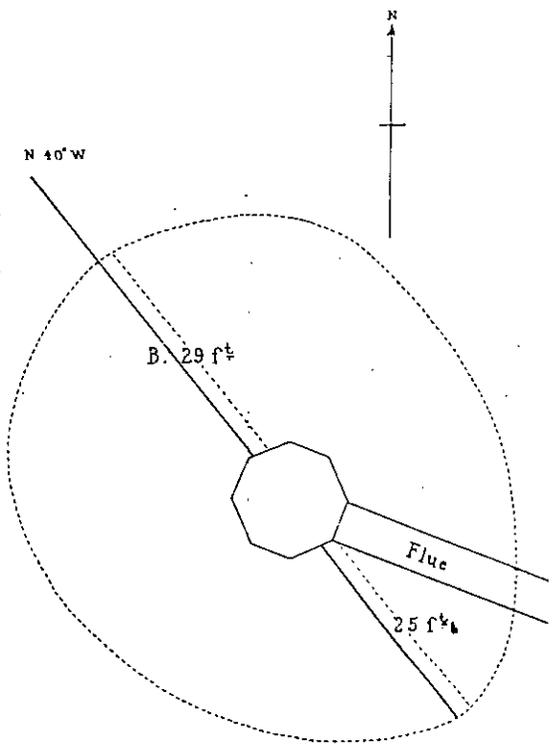


Mill Chimney
B = position of coping iron

Scale 1/8 Inch = 1 ft

GROUND PLANS

Showing space occupied by debris
Fig 2



Factory Chimney
B = position of coping iron

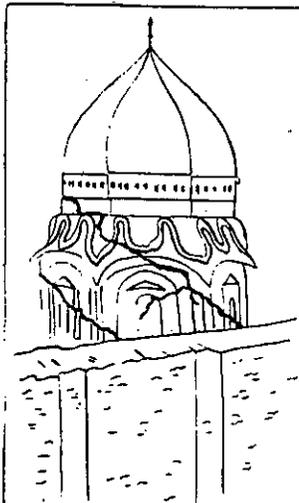


Fig. 3.

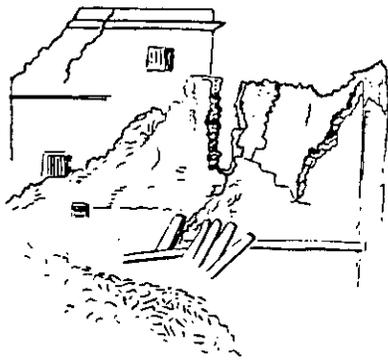


Fig. 4

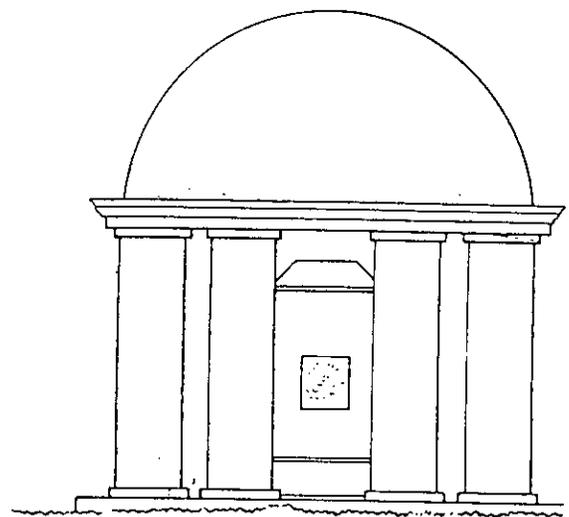


Fig 5.

Fig 6.

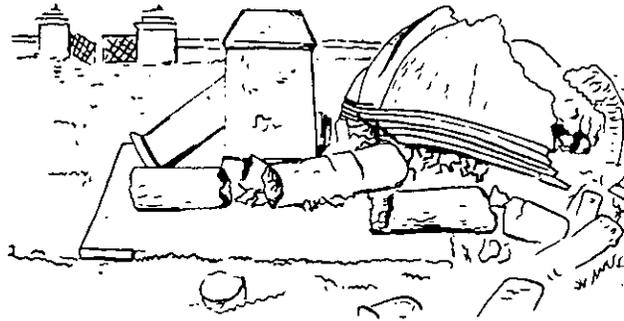


Fig 8

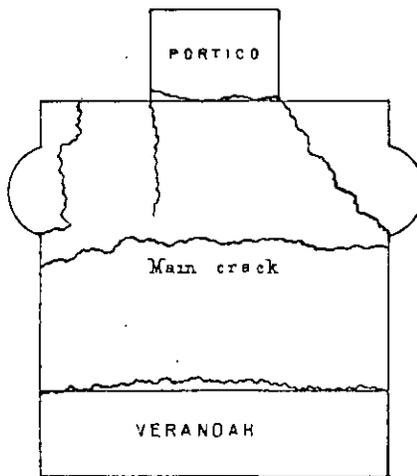


Fig 7.

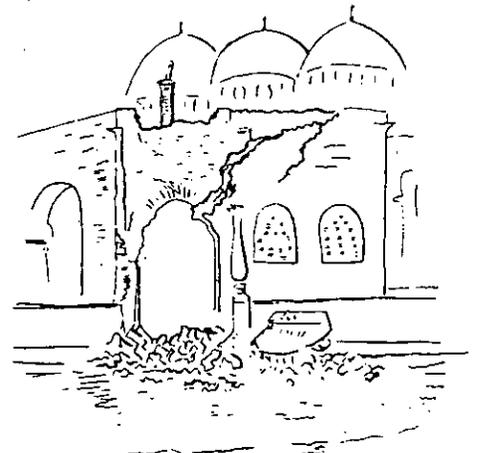
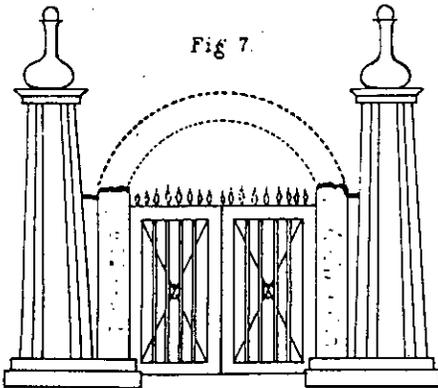


Fig 9.

On Steel by S.K.Hossain.

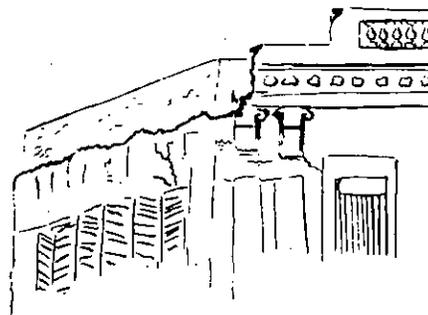


Fig 10.

**PHOTOGRAPHS AND FIGURES OF 1897 GREAT INDIAN
EARTHQUAKE**

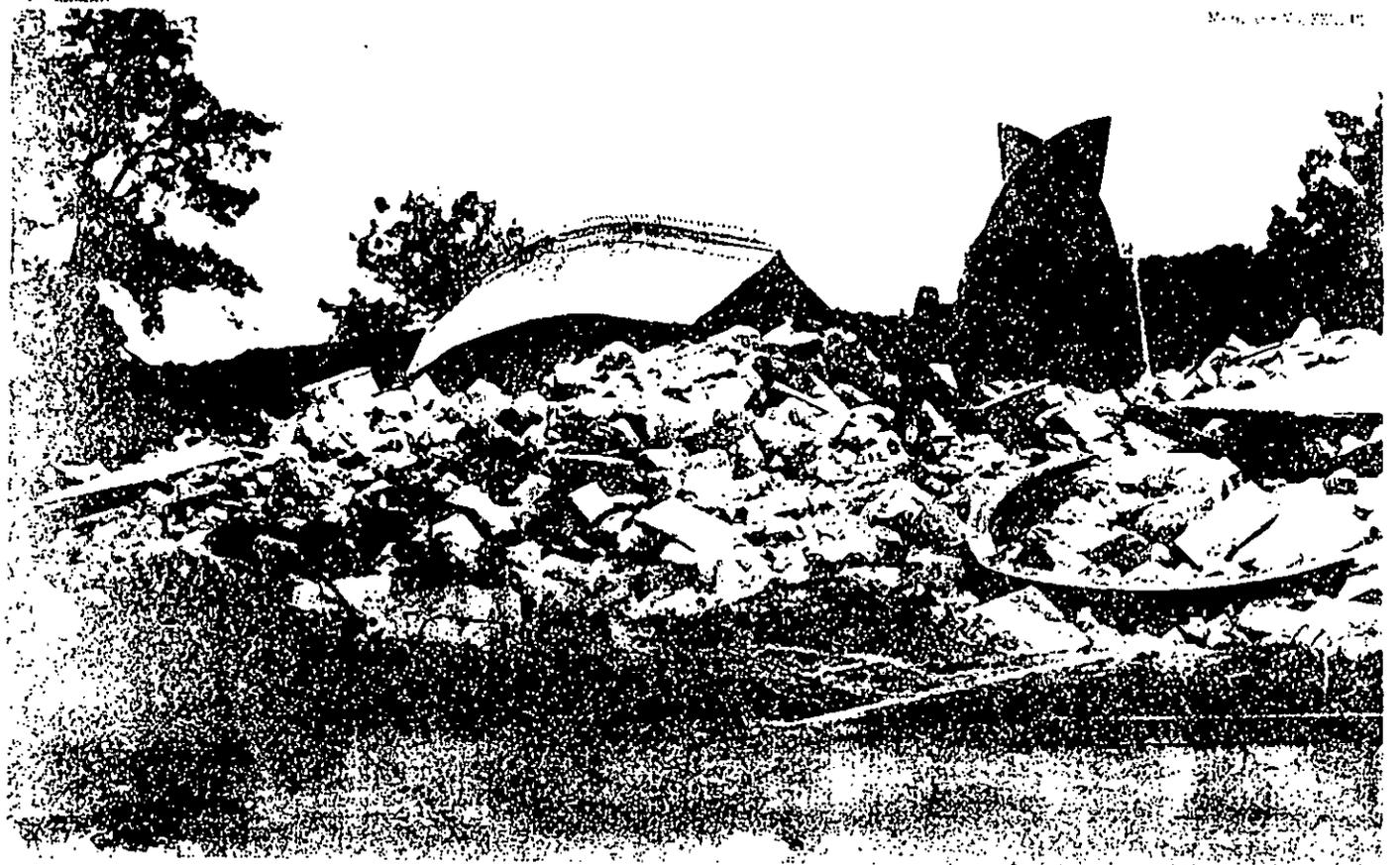




photo.

Photo of Survey Station at Bangaya, 1957

BENT RAILS AT BANGAYA S.I. 1957. (S. HARAHARDJAN)

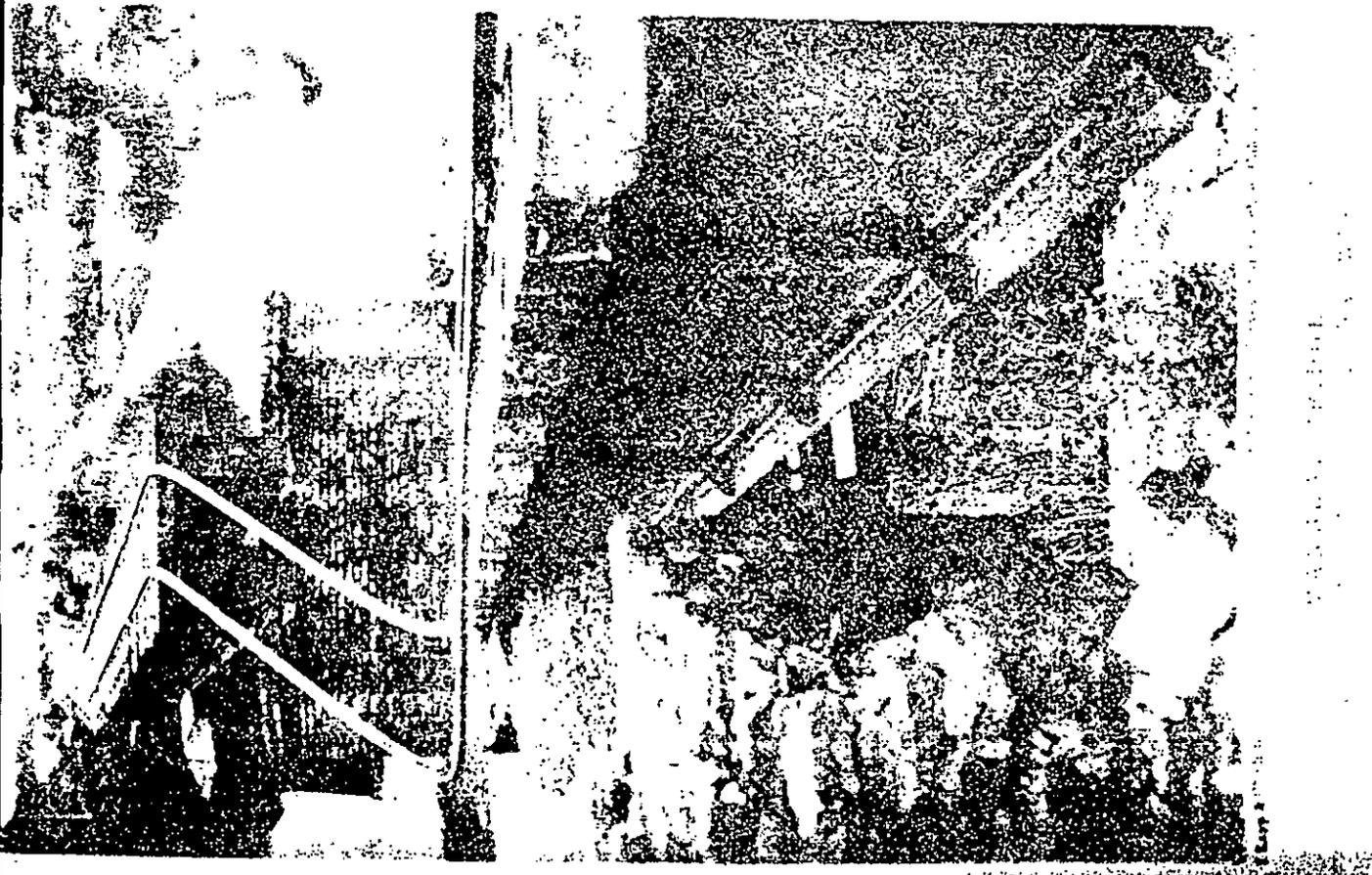




FIG. 4. TENT CAMP, SHILLONG, 1905.



FIG. 5. TENT CAMP, SHILLONG, 1905.

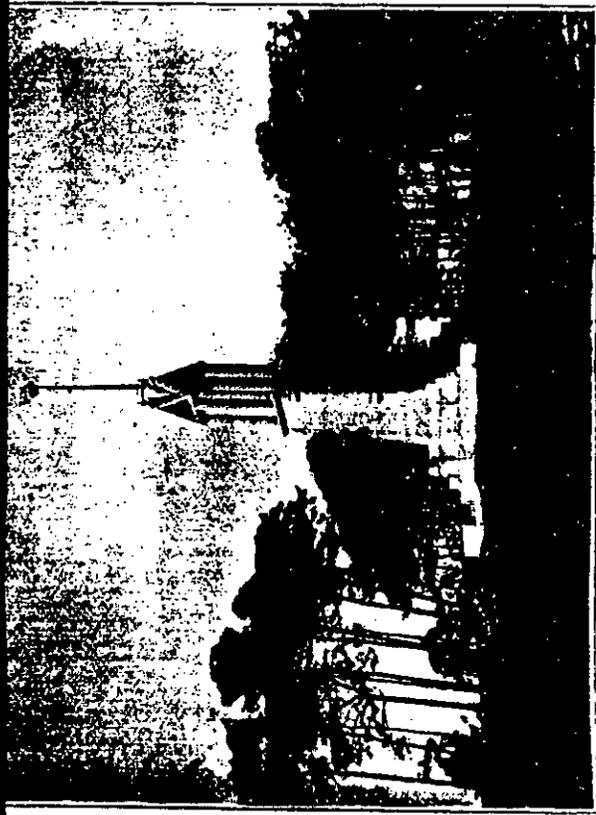


FIG. 6. COLLEGE, SHILLONG, 1905.



FIG. 7. THE SAME, AFTER THE BURNING, 1905.

Survey of India Office, Calcutta, June 1905.

Photographed by Mr. G. S. ...



Fig. 1. Building destroyed by earthquake.

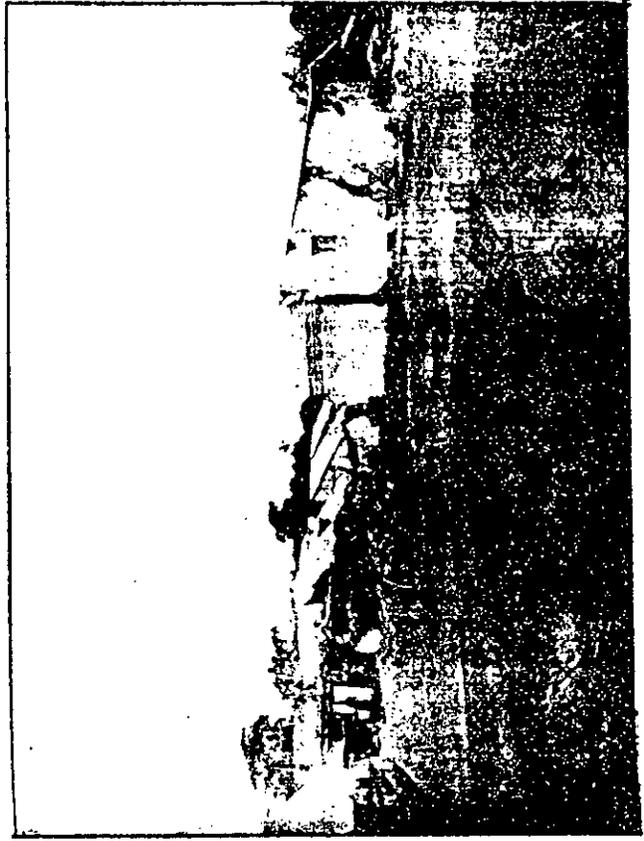


Fig. 2. Building destroyed by earthquake.

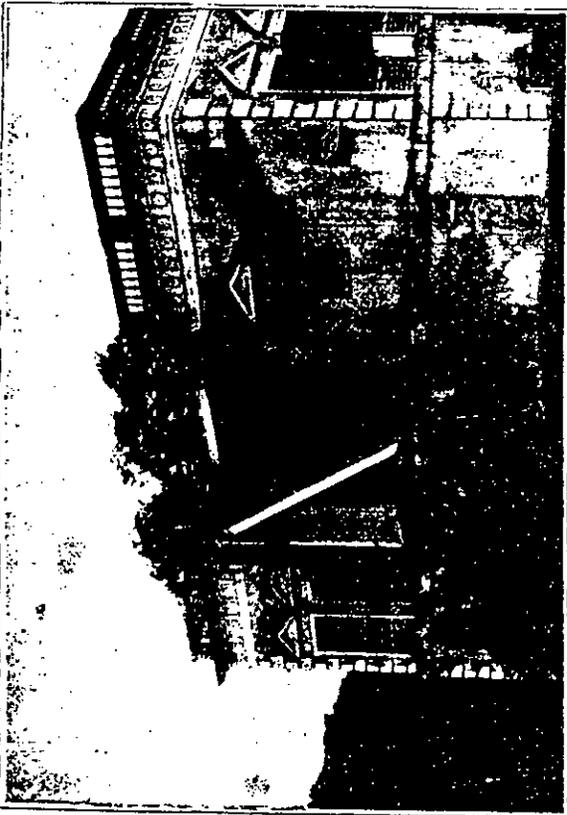


Fig. 3. Building destroyed by earthquake.



Fig. 4. Building destroyed by earthquake.

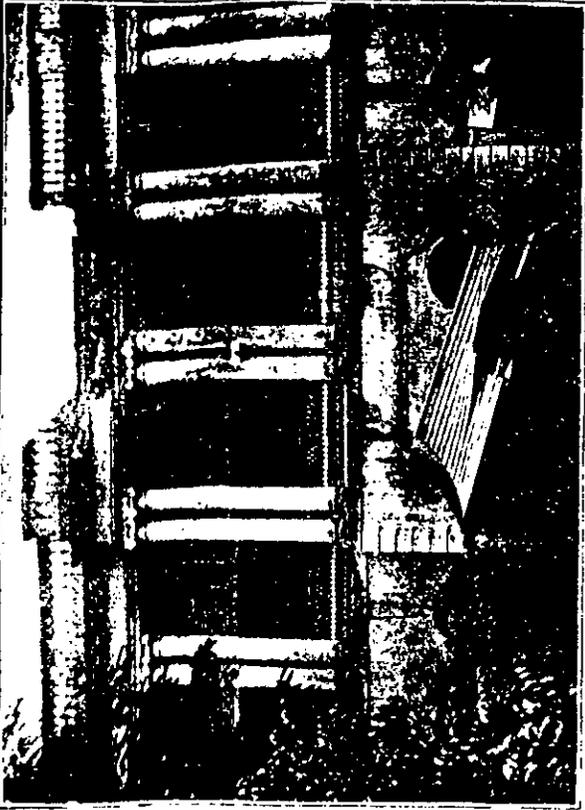


FIG. 1. GOVERNMENT SECRETARIAT, CALCUTTA.

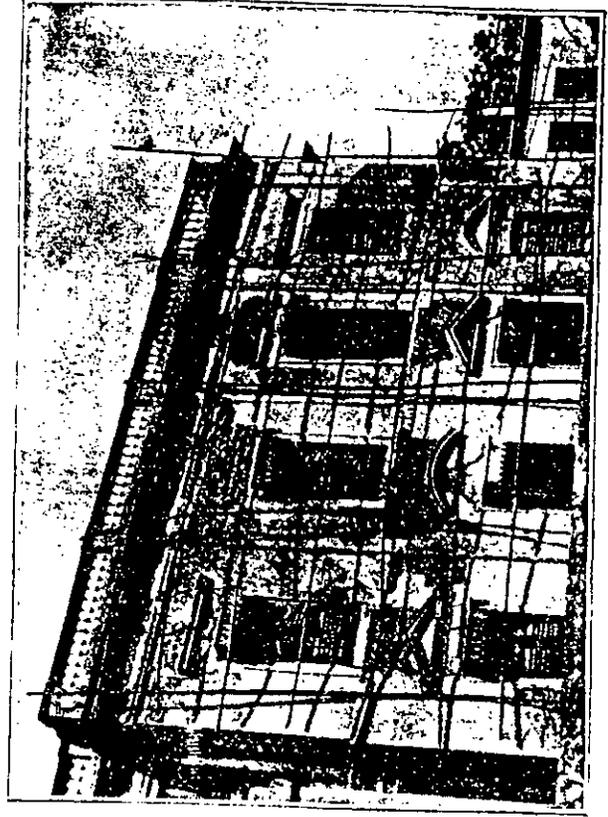


FIG. 2. GOVERNMENT SECRETARIAT, CALCUTTA.



FIG. 3. VICTORIA MEMORIAL, CALCUTTA.

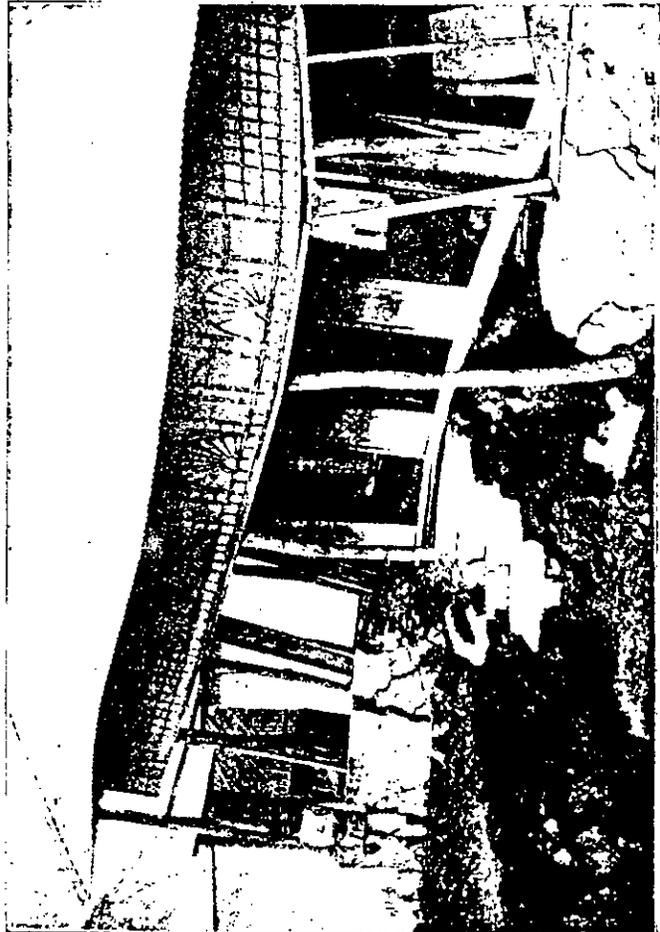


FIG. 4. VICTORIA MEMORIAL, CALCUTTA.

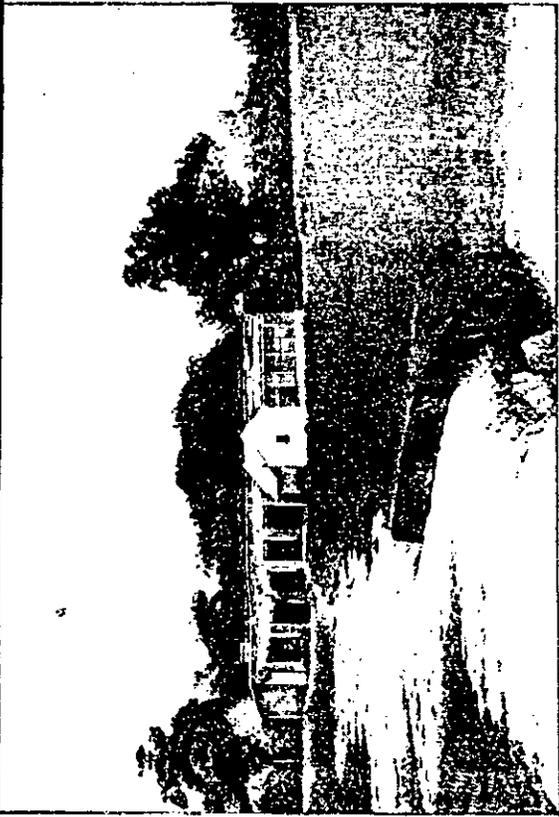


FIG. 1. THE WAREHOUSE AT JUTE MILL, SERADGUNA.

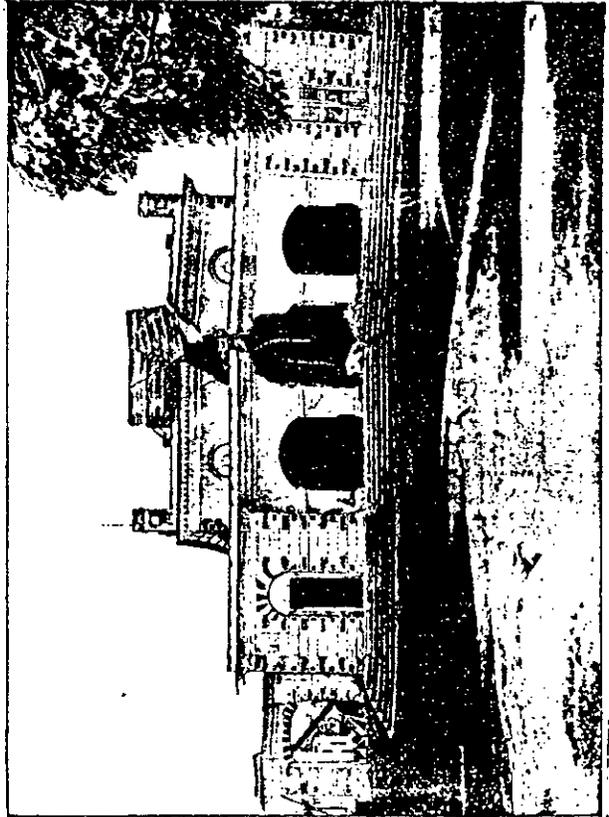


FIG. 2. MANAGER'S BUNGALOW AT JUTE MILL, SERADGUNA.

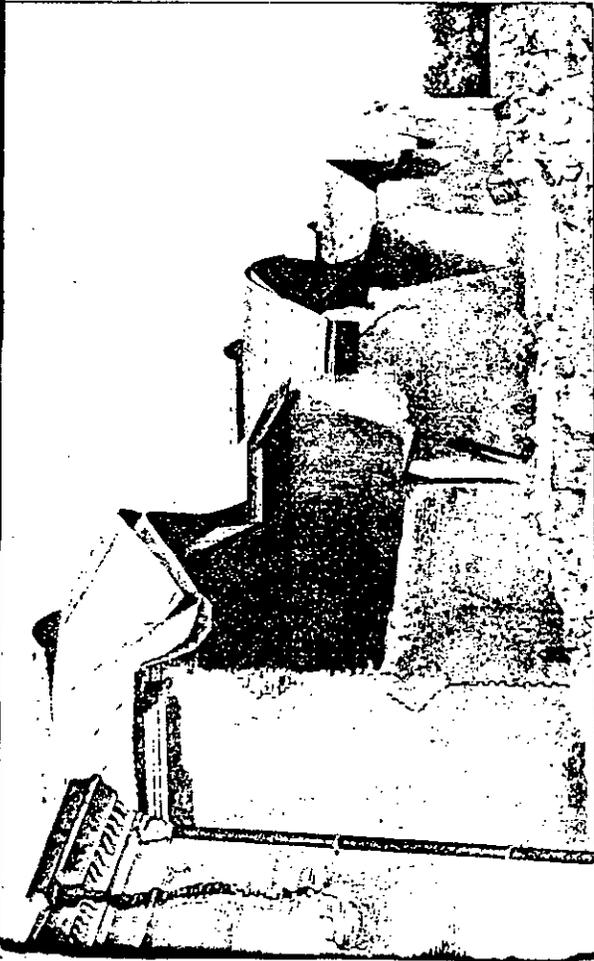


FIG. 3. GODDOWNS OF JUTE MILL, SERADGUNA.

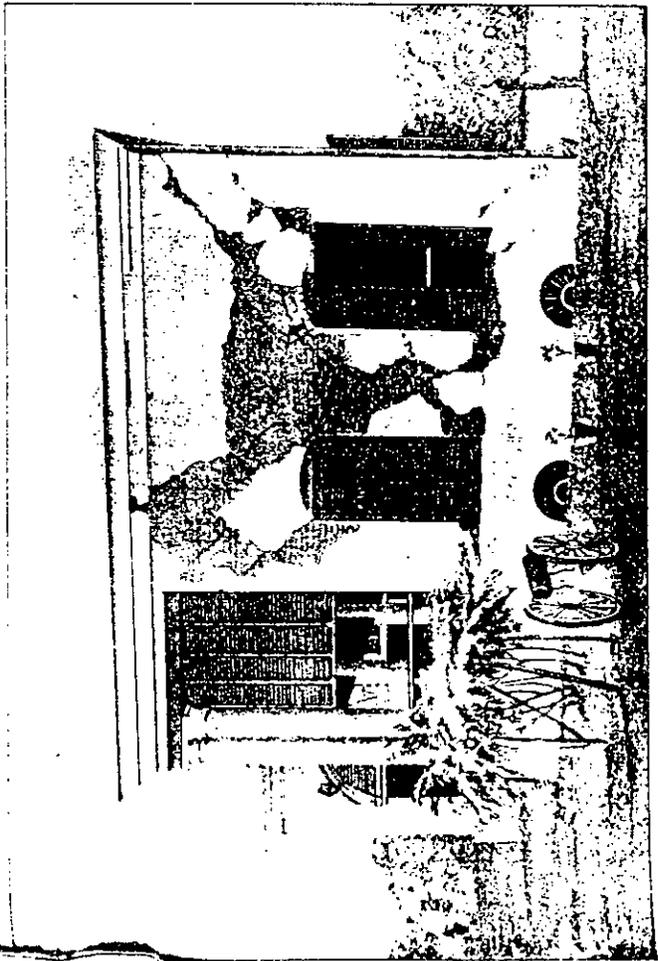


FIG. 4. MANAGER'S BUNGALOW AT JUTE MILL, SERADGUNA.

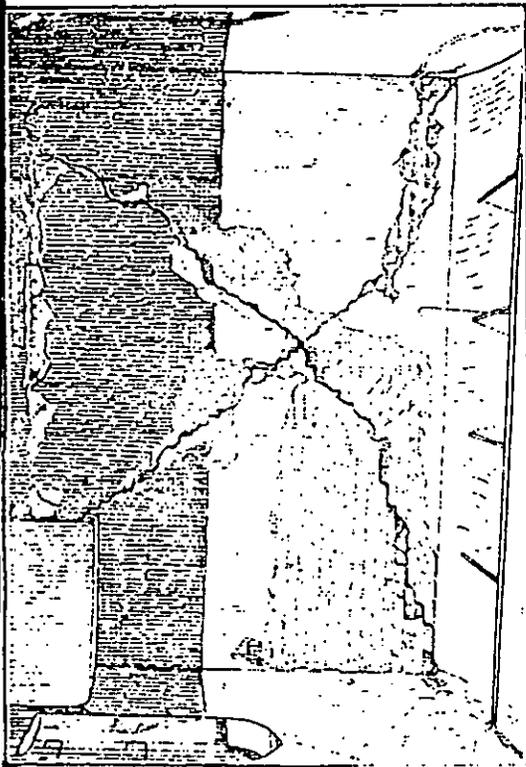
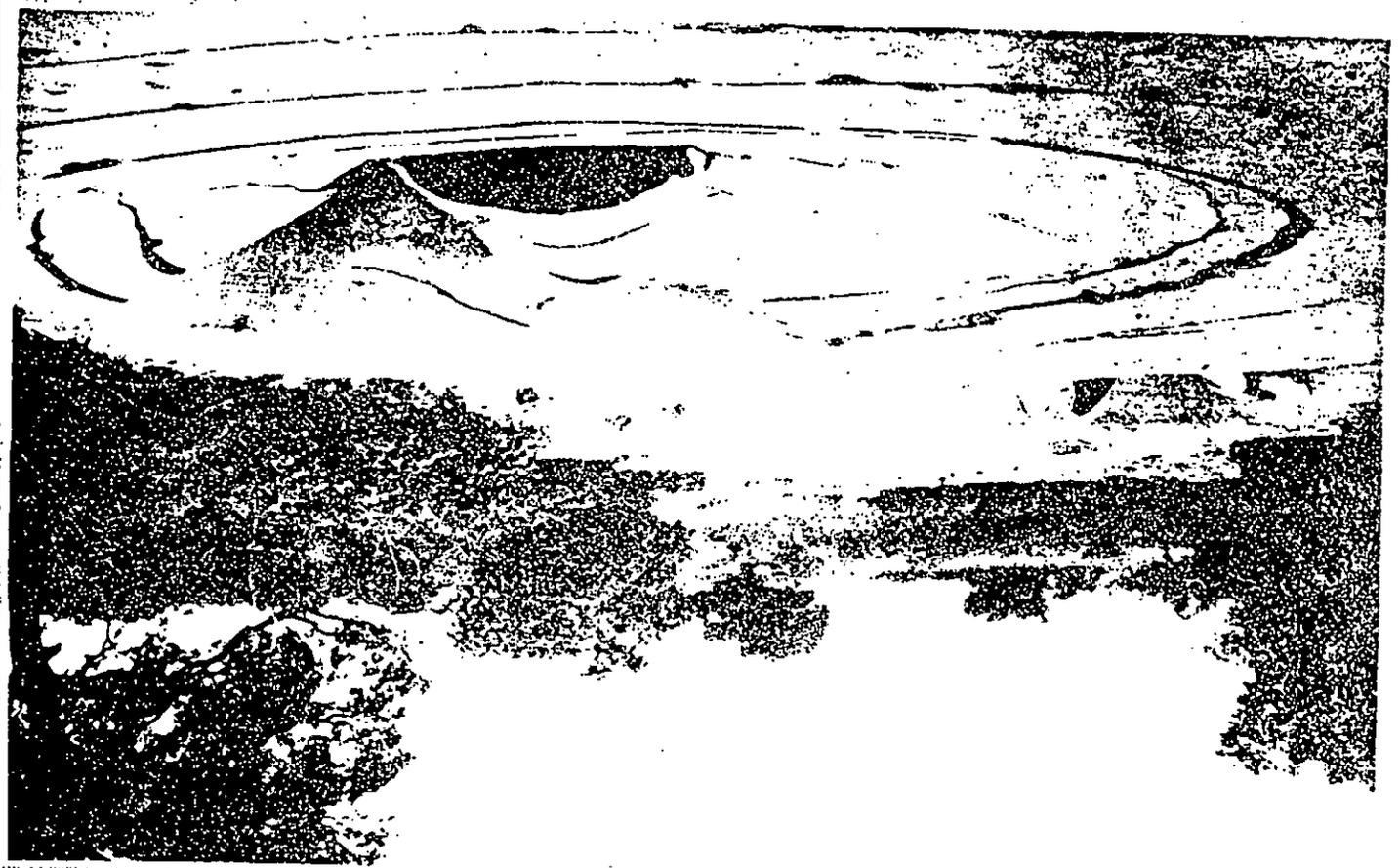
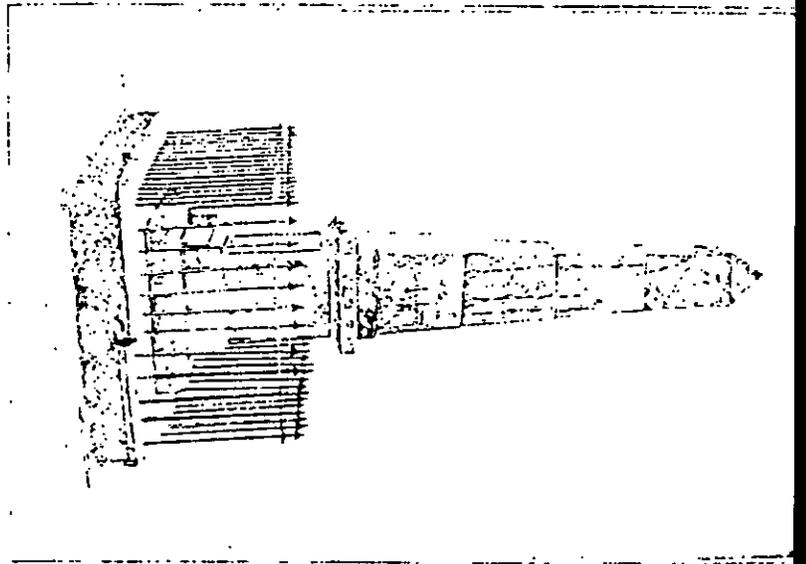


FIG. 1. SECTION OF THE TEMPLE OF KARNAK, THEBES, EGYPT.



**PHOTOGRAPHS AND FIGURES OF 1918 SRIMANGAL
EARTHQUAKE**

1



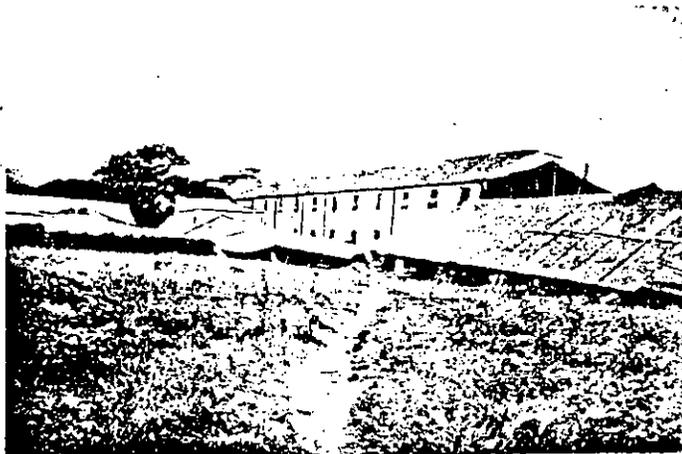
Photographs by Murray Stuart.

G. S. I. Calcutta.

FIG. 2. ASSISTANT'S BUNGALOW AT PUTTIACHARRA.



FIG. 1. EASTERN END OF FACTORY, DOLOI.



Photographs by Murray Stuart.

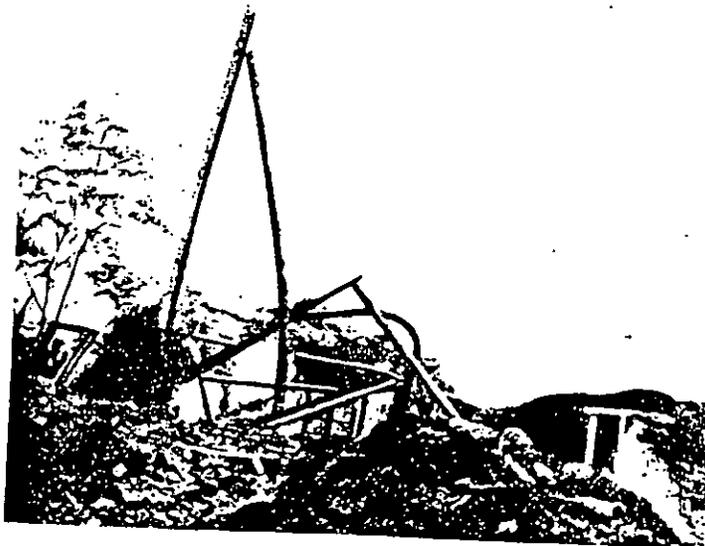
G. S. I. Calcutta.

FIG. 2. FALLEN LEAF-HOUSES, DOLOI.

U



FIG. 1. THE CLUB AT KALIGHAT.



Photographs by Murray Stuart.

G. S. I. Calcutta

FIG. 2. DR. MUMFORD'S BUNGALOW AT KALIGHAT.

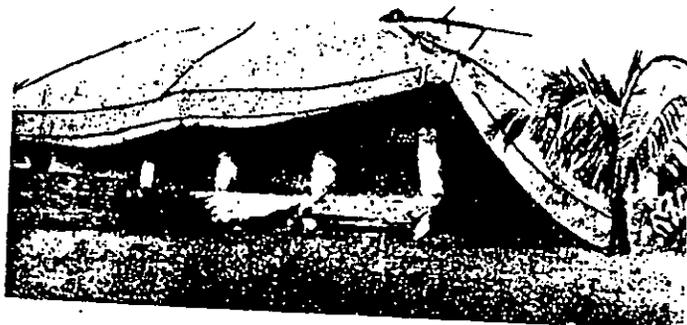


FIG. 1. MANAGER'S BUNGALOW AT PATRAKHALA.

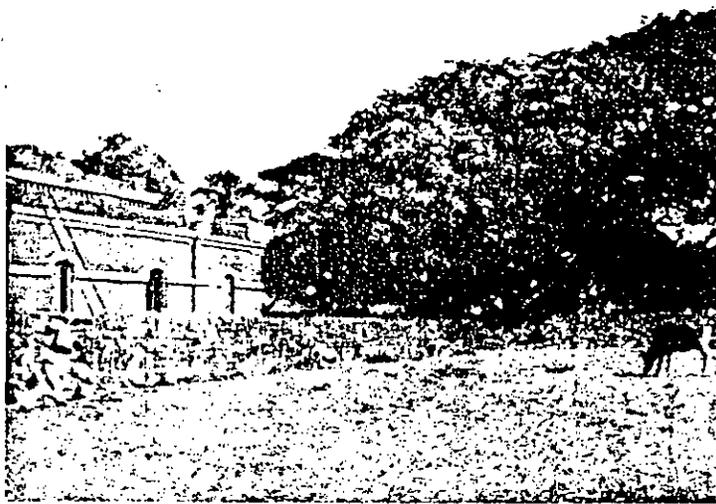


FIG. 1. STACK OF BRICKS AT KISHORGANJ.



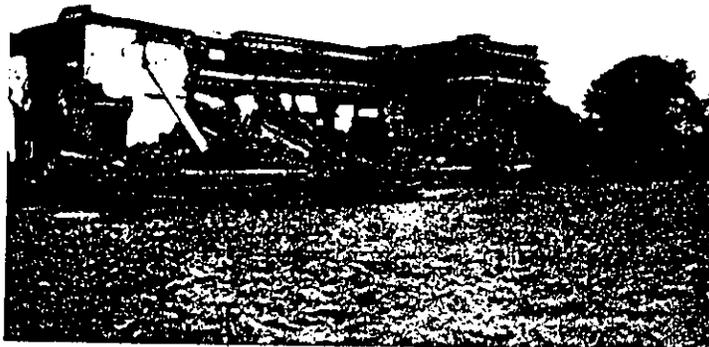
Photographs by Murray Stuart.

G. S. I. Calcutta.

FIG. 2. SUB-DIVISIONAL OFFICER'S BUNGALOW AT KISHORGANJ.



FIG. 1. STACK OF BRICKS AT KISHORGANJ.



Photographs by Murray Stuart.

G. S. I. Calcutta.

FIG. 2. SUB-DIVISIONAL OFFICER'S BUNGALOW AT KISHORGANJ.

**PHOTOGRAPHS AND FIGURES OF 1930 DHUBRI
EARTHQUAKE**

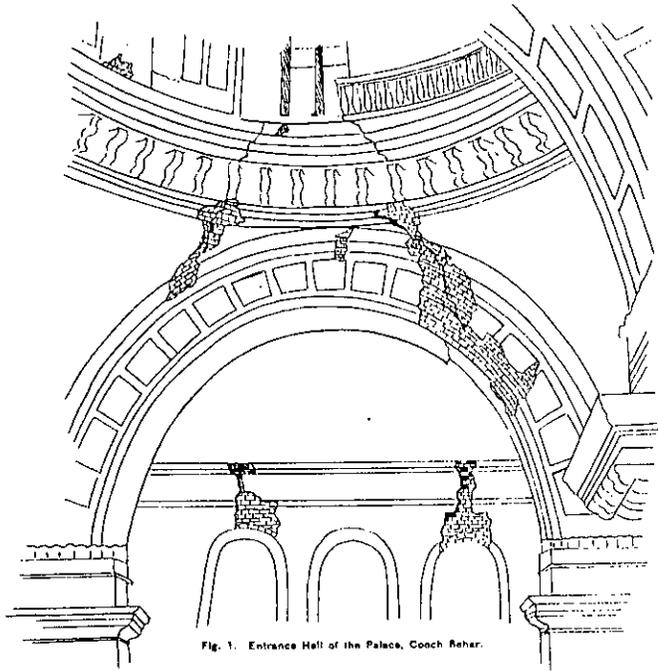


Fig. 1. Entrance Hall of the Palace, Cooch Behar.

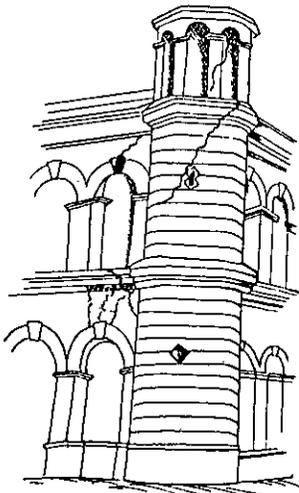


Fig. 2. Vice-President's House, Cooch Behar.

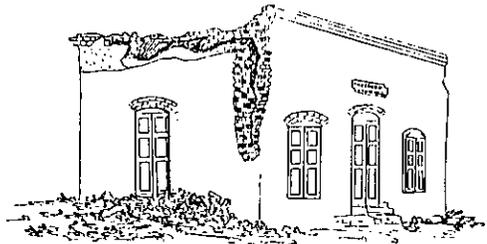


Fig. 3. Berrie Club, Sapatgram.

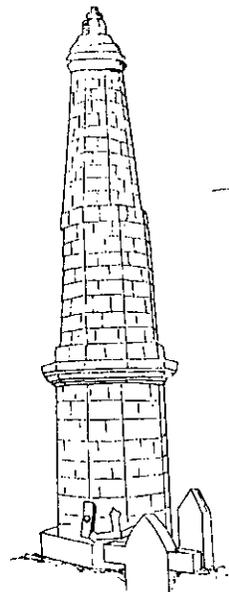


Fig. 4. Monument in New Graveyard, Cherrapunji.

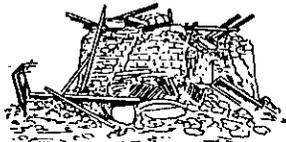


Fig. 6. Picket Post No. 20, Buxa Fort.



Fig. 8. Tombstone, Tura Cemetery.

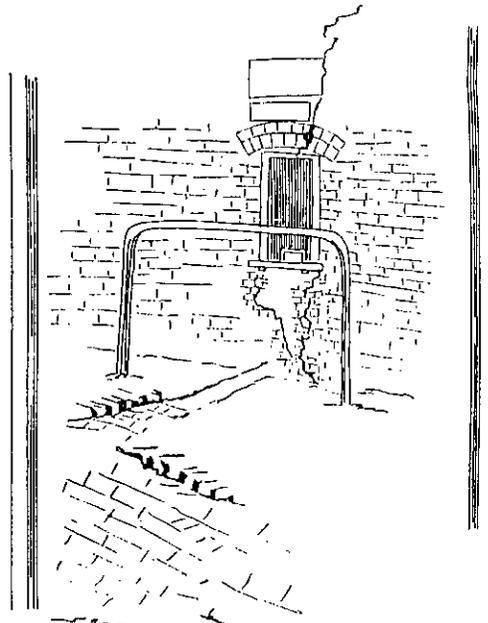


Fig. 9. Smoking Hall, Gauripur Station.

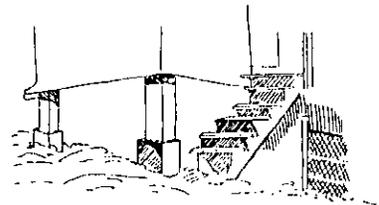
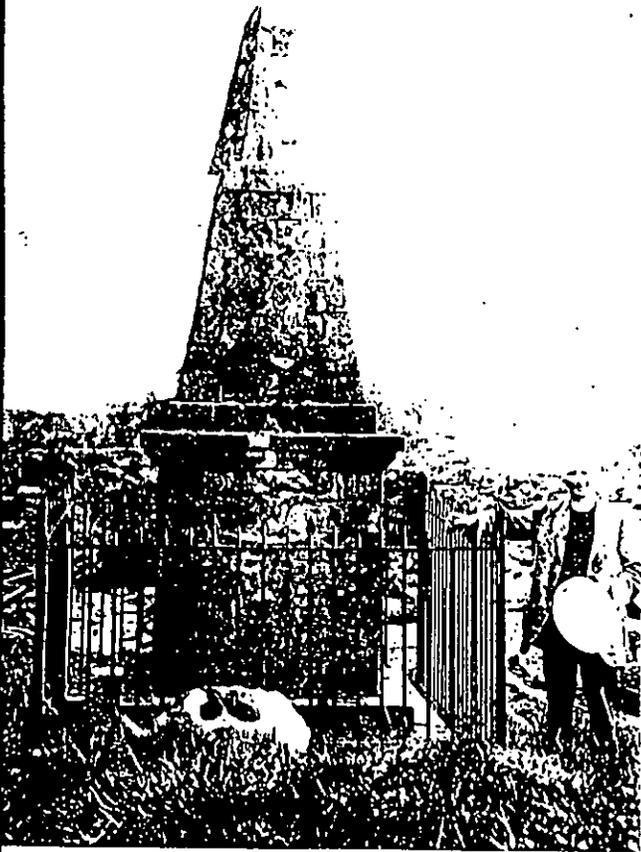


Fig. 5. Mission Building, Tura.



Fig. 7. Marble Cross, Tura Cemetery.



E. R. Gee, Photos.

FIG. 1. MONUMENT TO THE REV. JOHN ROBERTS,



G. S. J., Calcutta.

FIG. 2. MONUMENT IN NEW GRAVEYARD. CHERRAPIIN.H

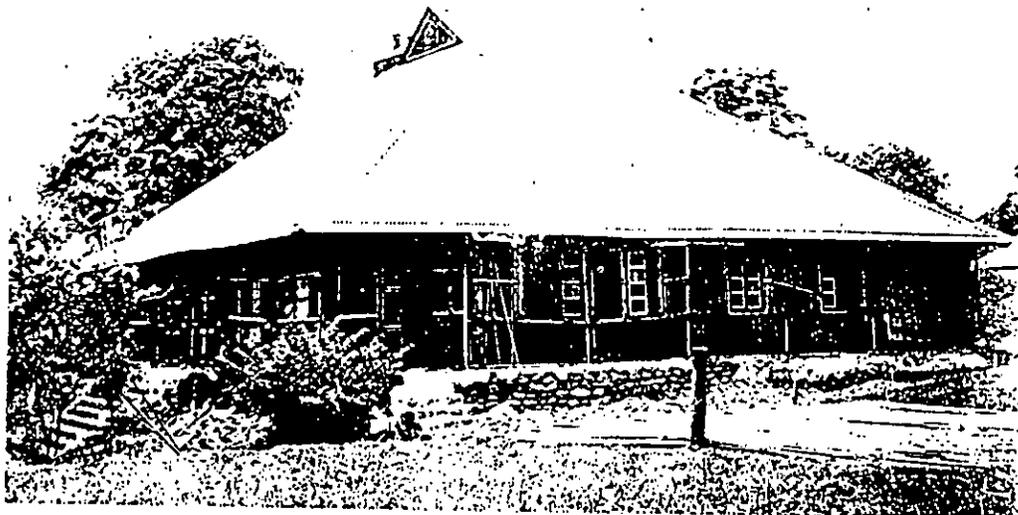
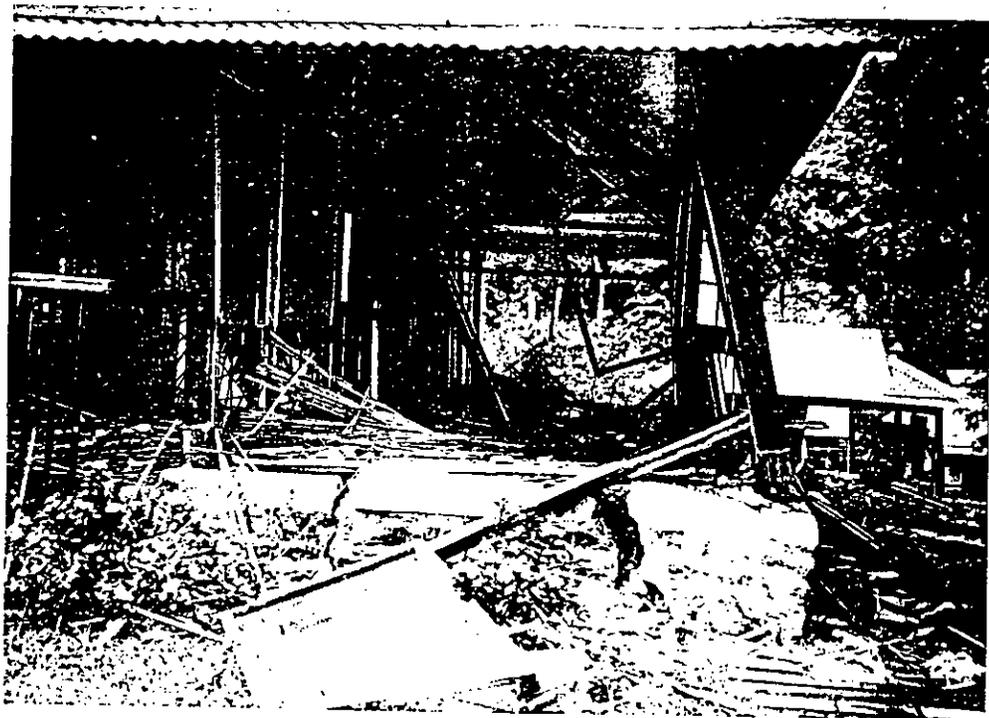


FIG. 1. THE CIVIL SURGEON'S BUNGALOW, TURA.

V-10
5/10/10



E. R. Gee, Photos.

G. S. I., Calcutta.

FIG. 2. NORTHERN END OF THE EXTRA ASSISTANT COMMISSIONER'S BUNGALOW, TURA.



J. N. E. Nagle, Photo.

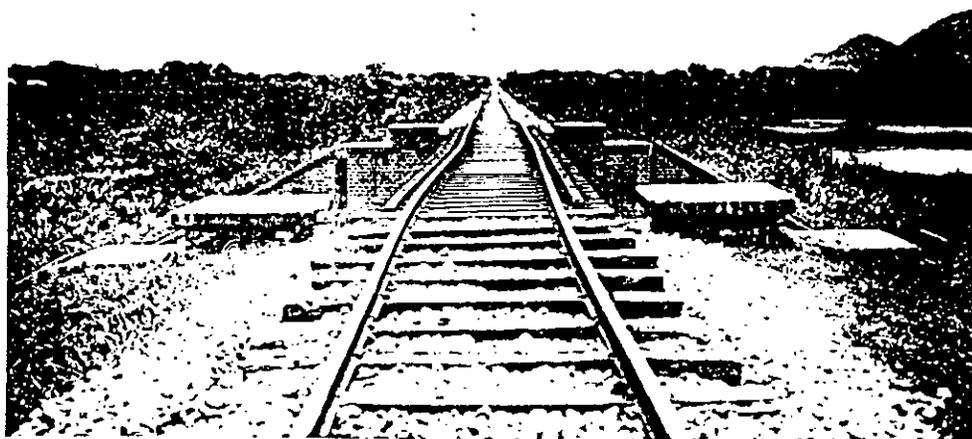
G. S. I., Calcutta.

SAND-CRATERS NEAR GAURIPUR STATION, EASTERN BENGAL RAILWAY.



J. N. E. Nagle, Photo.

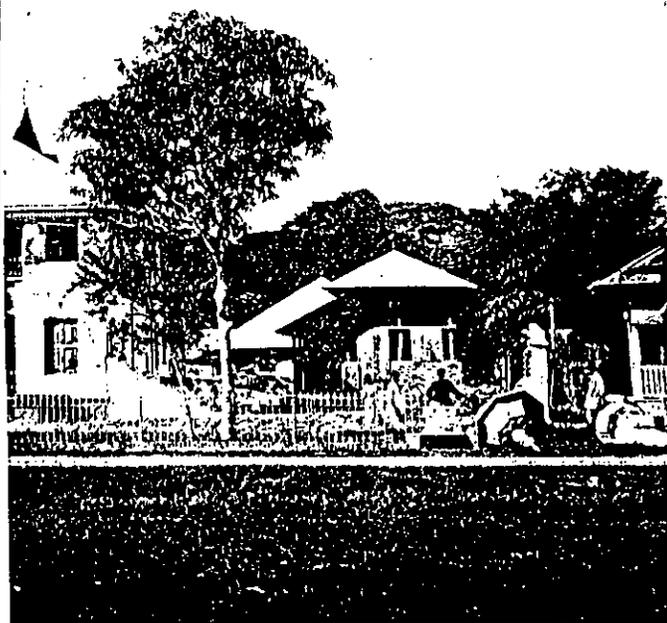
FIG. 1. RAILWAY-LINE NEAR DHUBRI, EASTERN BENGAL RAILWAY.



A. Lister-Jackson, Photo.

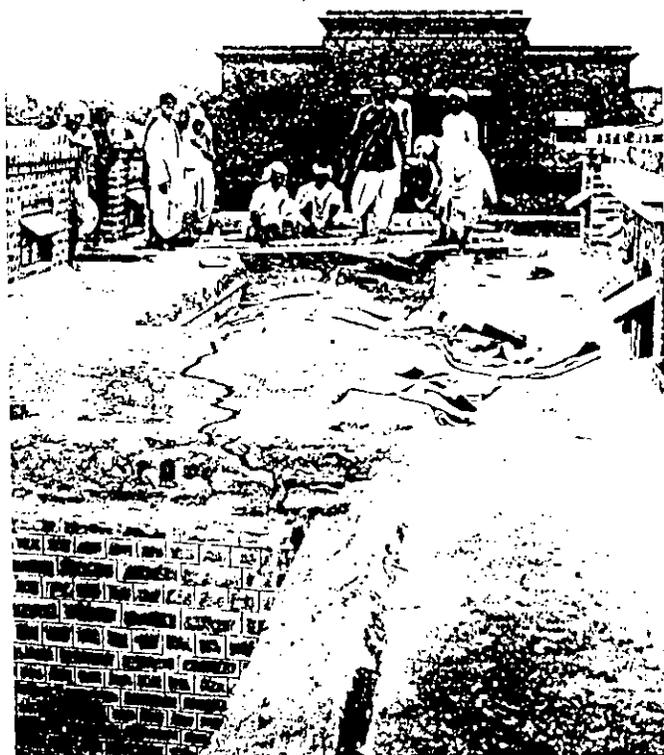
G. S. I., Calcutta.

FIG. 2. VIEW LOOKING EAST TOWARDS BASUGAON STATION, EASTERN BENGAL RAILWAY.



E. R. Gee, Photo.

FIG. 1. DISLODGED GATE PILLARS, DHUBRI.



J. N. E. Nagle, Photo.

G. S. I., Calcutta.

FIG. 2. ROOF OF GENERAL OFFICE, E. B. RY., LALMANIRHAT.

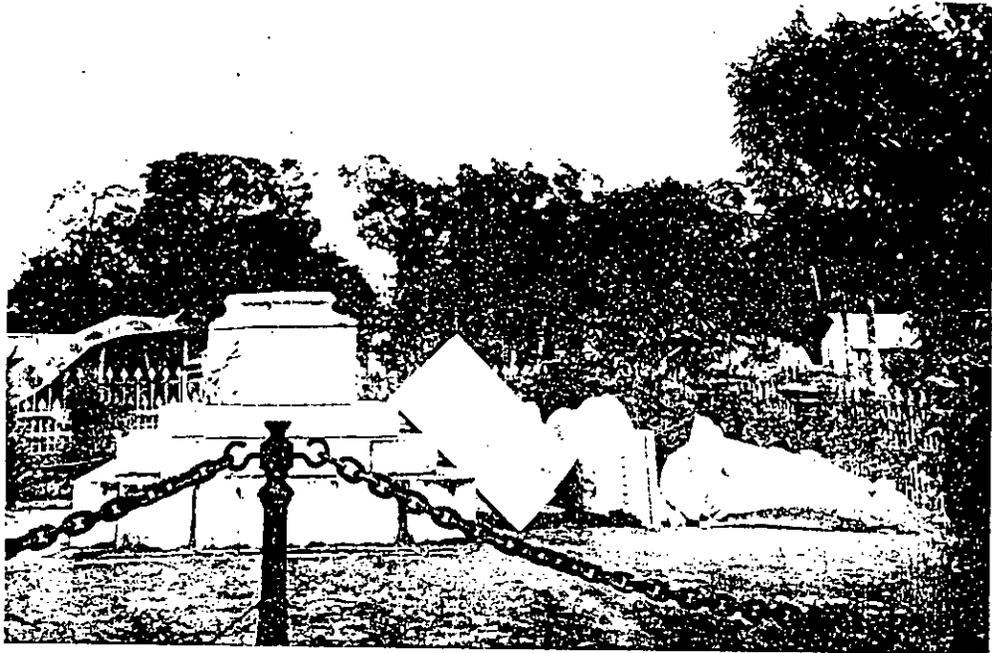
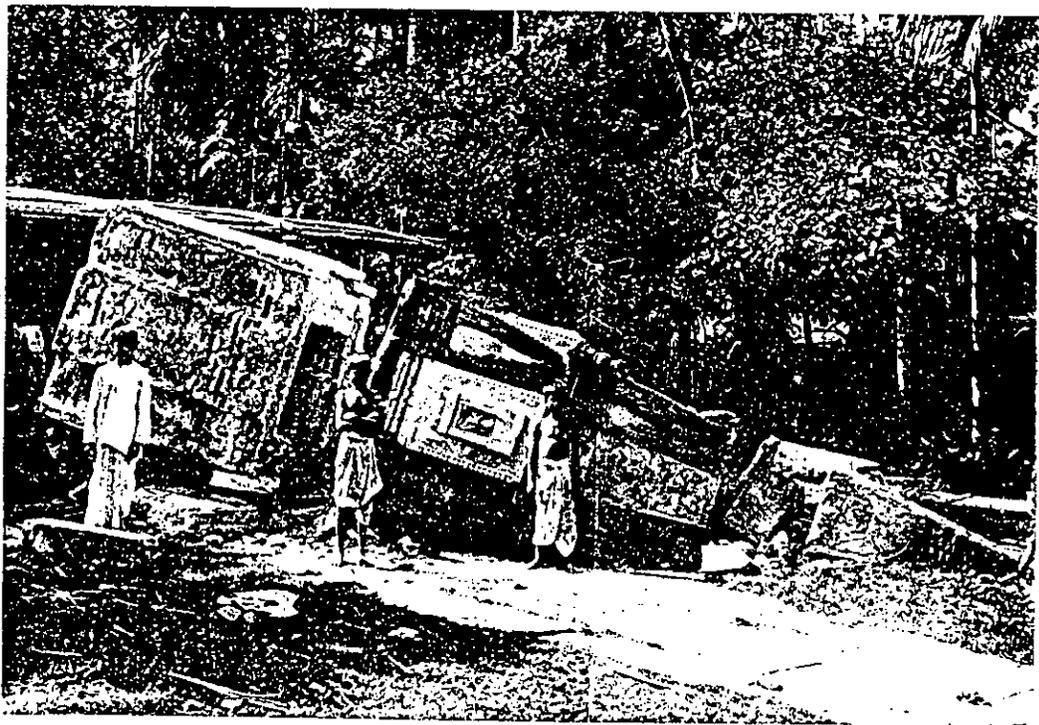


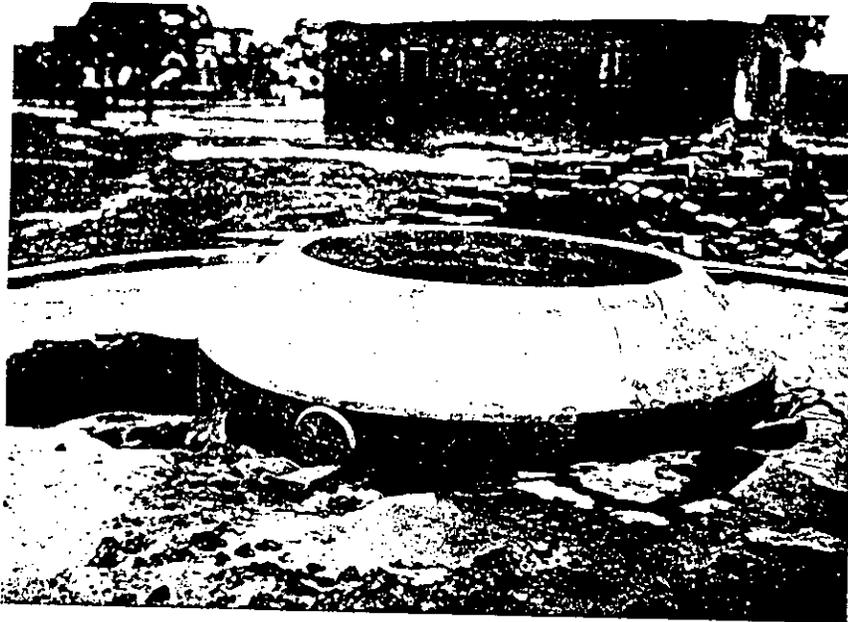
FIG. 1. QUEEN'S STATUE, DHUBRI.



E. R. Gee, Photos.

FIG. 2. SHIVA TEMPLE, DHUBRI.

G. S. I., Calcutta.



J. N. E. Nagle, Photo.

FIG. 1. OFFICE WELL AT LALMANIRHAT, EASTERN BENGAL RAILWAY.



E. R. Gee, Photo.

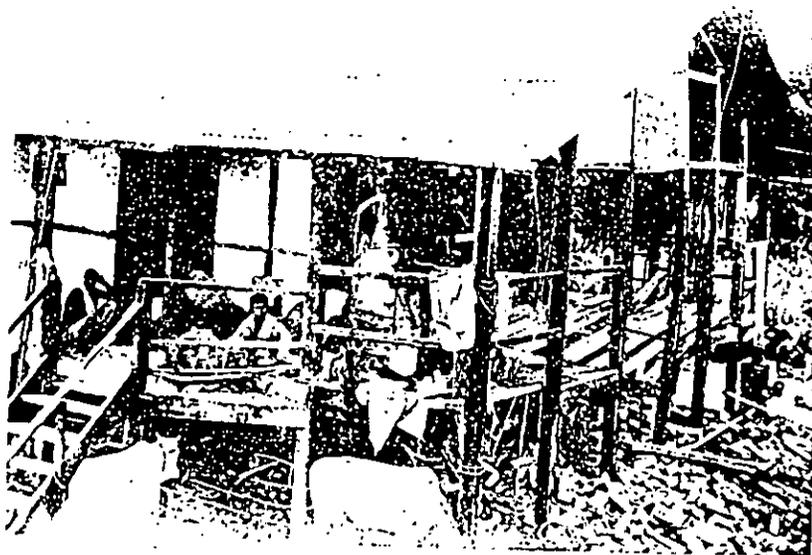
FIG. 2. KAKINA KOTHI, RANGPUR.

G. S. I., Calcutta.



E. R. Gee, Photo.

FIG. 1. BUNGALOWS OF THE FOREST DEPARTMENT, DHUBRI.

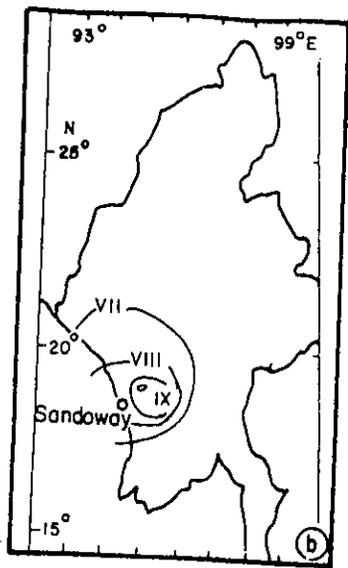


J. N. E. Nagle, Photo.

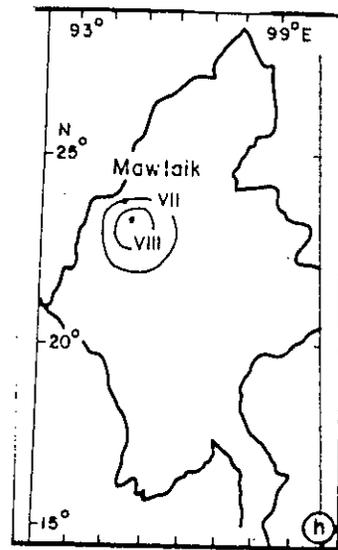
G. S. I., Calcutta.

FIG. 2. CHUNG QUARTERS AT KOKRAJHAR, EASTERN BENGAL RAILWAY.

APPENDIX-D
ORIGINAL ISOSEISMAL MAPS OF 13 EVENTS



22/1/75



16/1/75

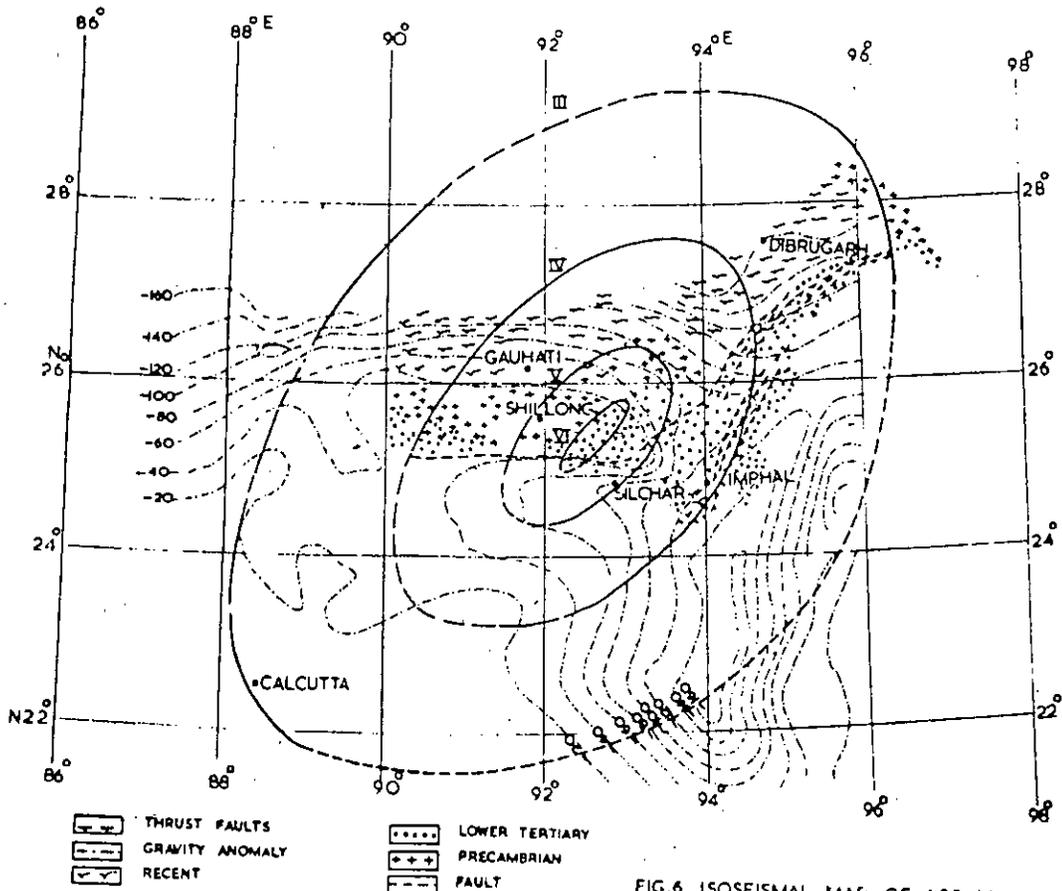


FIG. 6 ISOSEISMAL MAP OF ASSAM EARTHQUAKE OF JULY 8, 1975

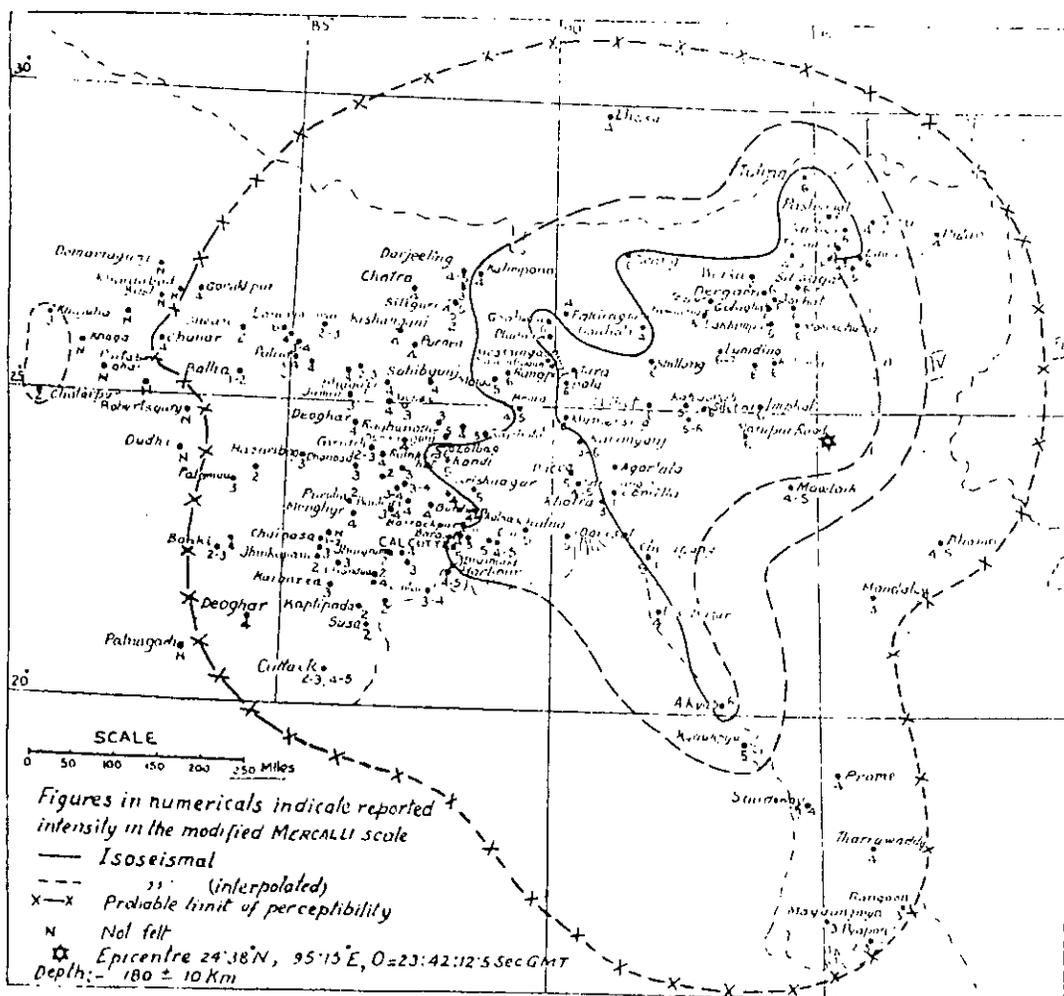
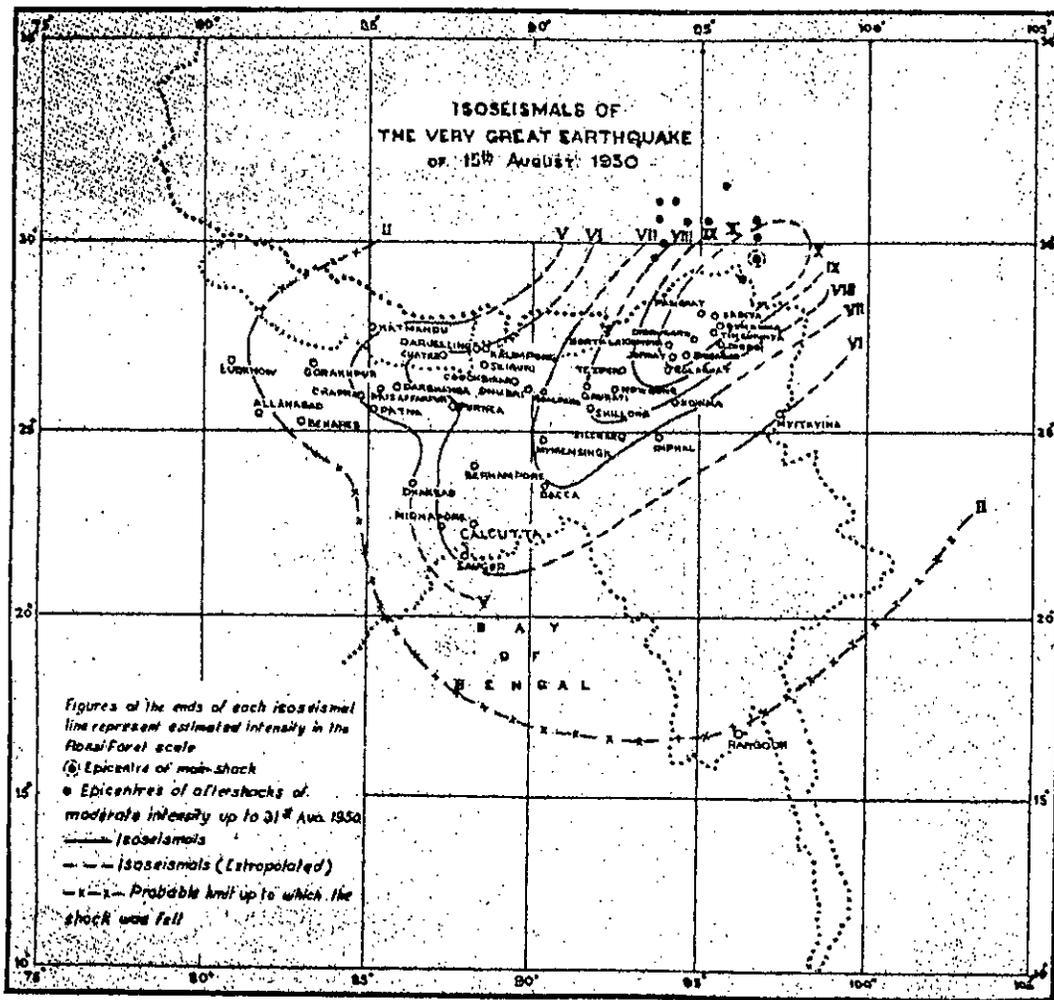


Fig. 1. Isoseismal map of the earthquake, 1950

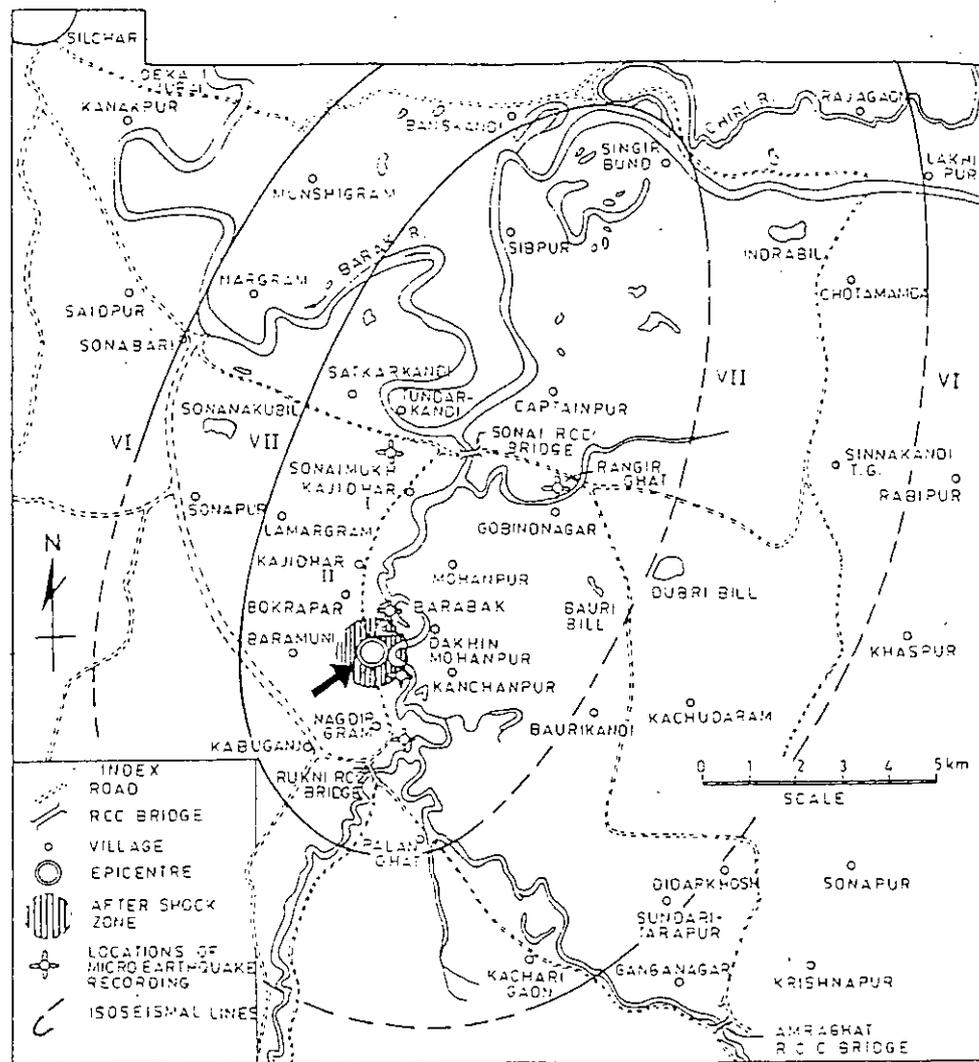


Fig. Isoseismal Map, location of Microearthquake recording and Aftershock Zone, 1988

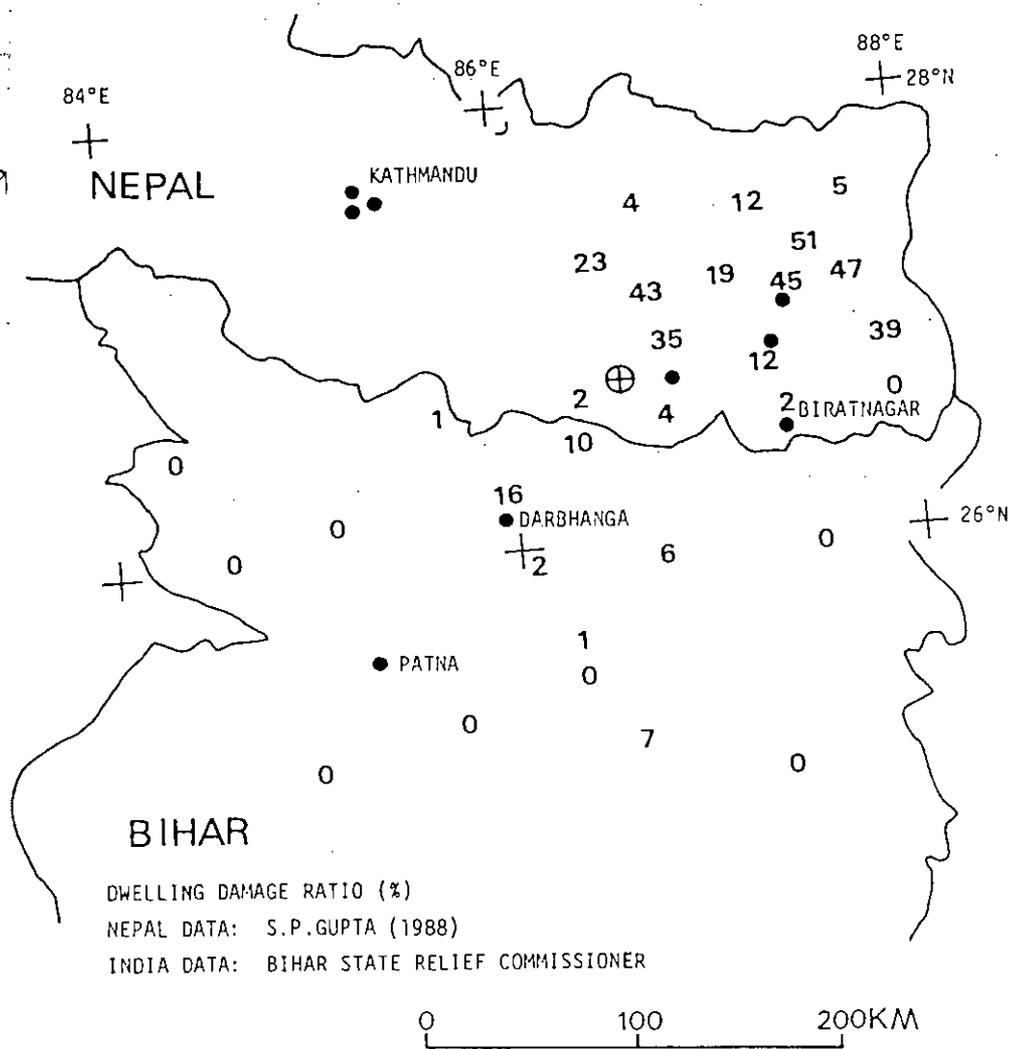
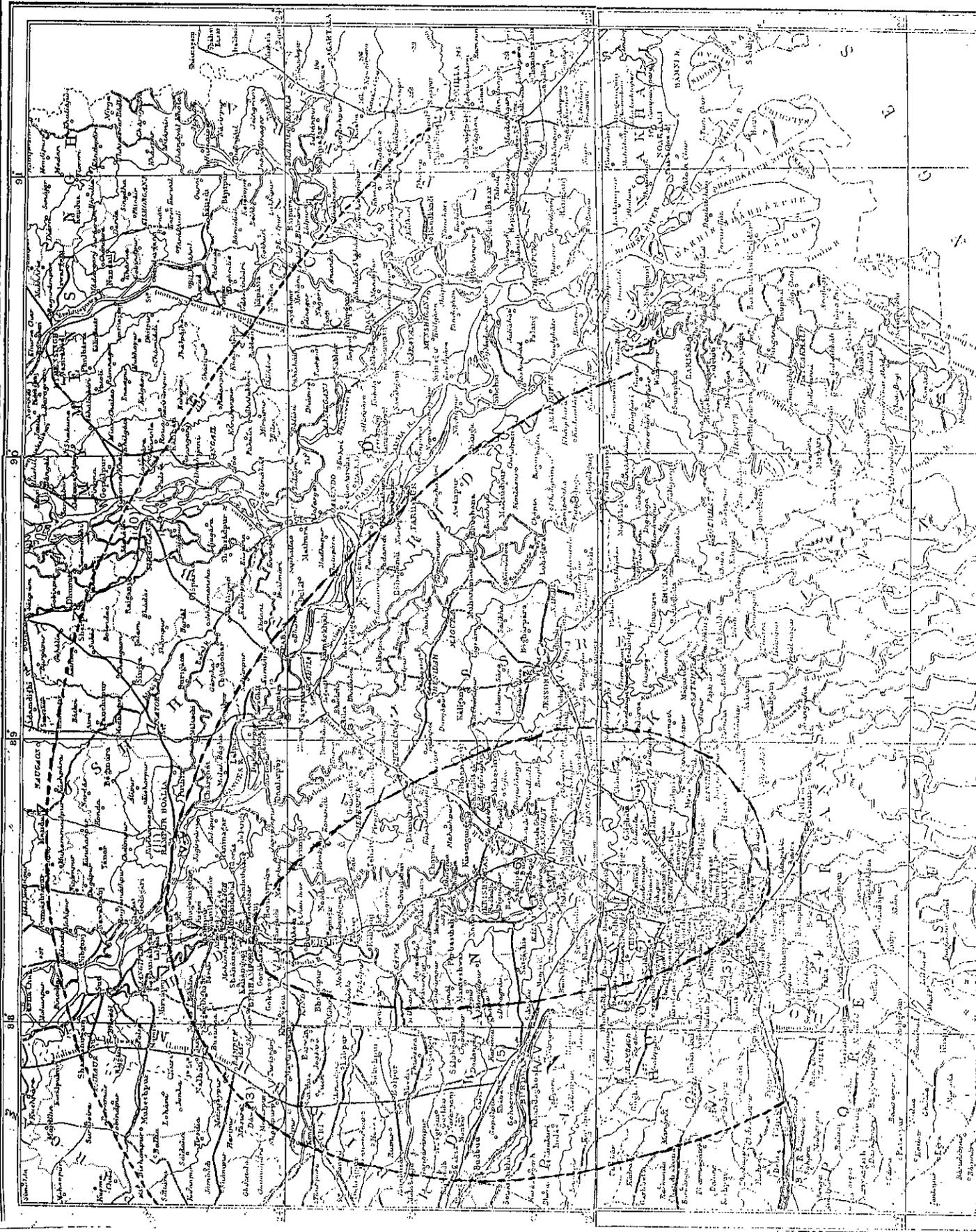
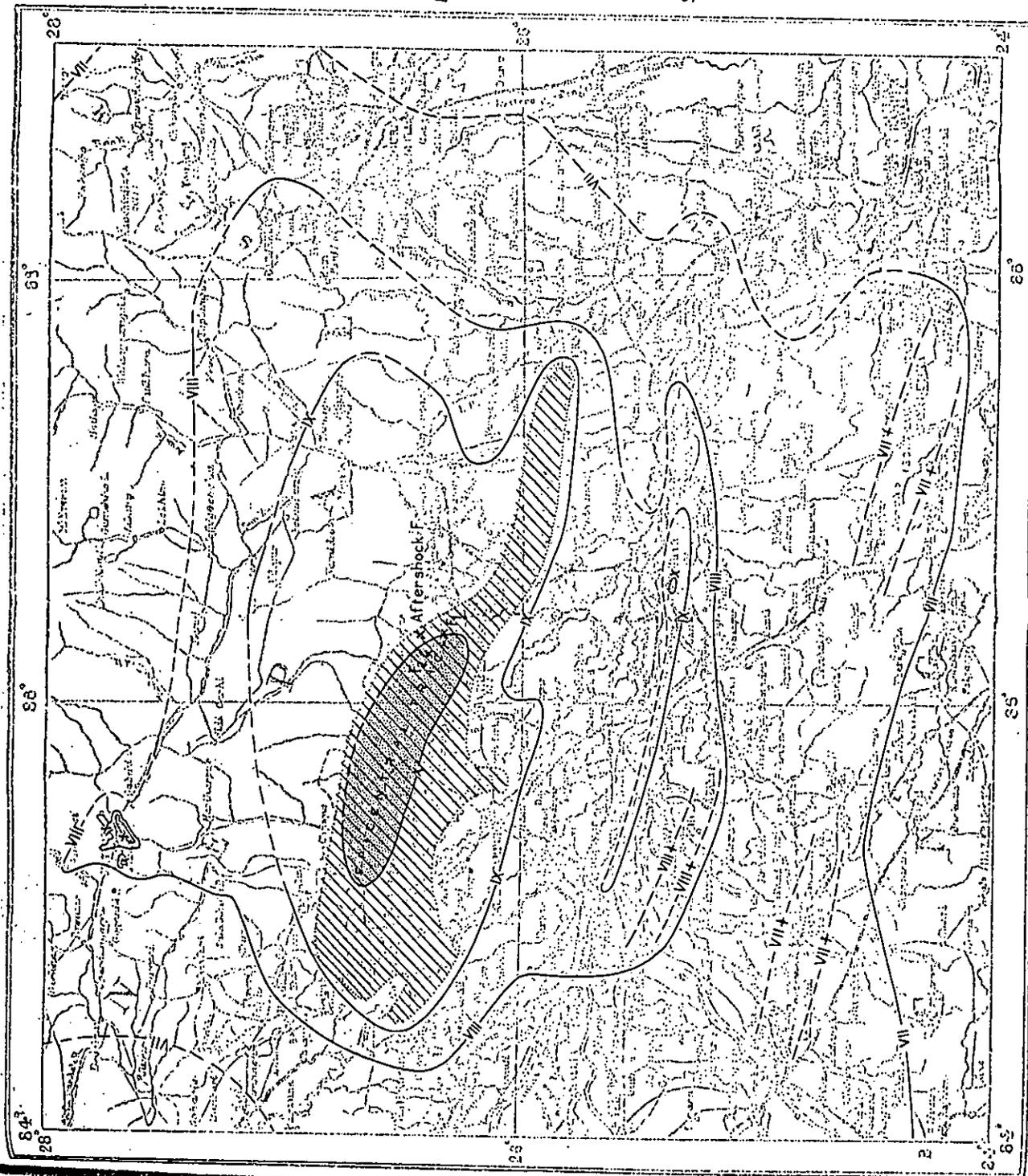


Fig. Map of the affected region showing dwelling damage ratios





INDEX.

-  Isoseismal X
-  Slump belt

The isoseismal lines are based on the Mercalli scale.

F₁—Focus of initial failure, main shock.

F₂—Focus of major failure, main shock.

After-shock F—Focus of aftershock of January, 19th.

Scale, 1 inch = 32 miles.
1 : 2,000,000.

THE HIGHER ISOSEISMALS OF THE EARTHQUAKE OF THE 15TH JANUARY, 1934.

G. S. A. California.

Based upon Survey of Inland maps 22 & 23, with the permission of the Surveyor General.

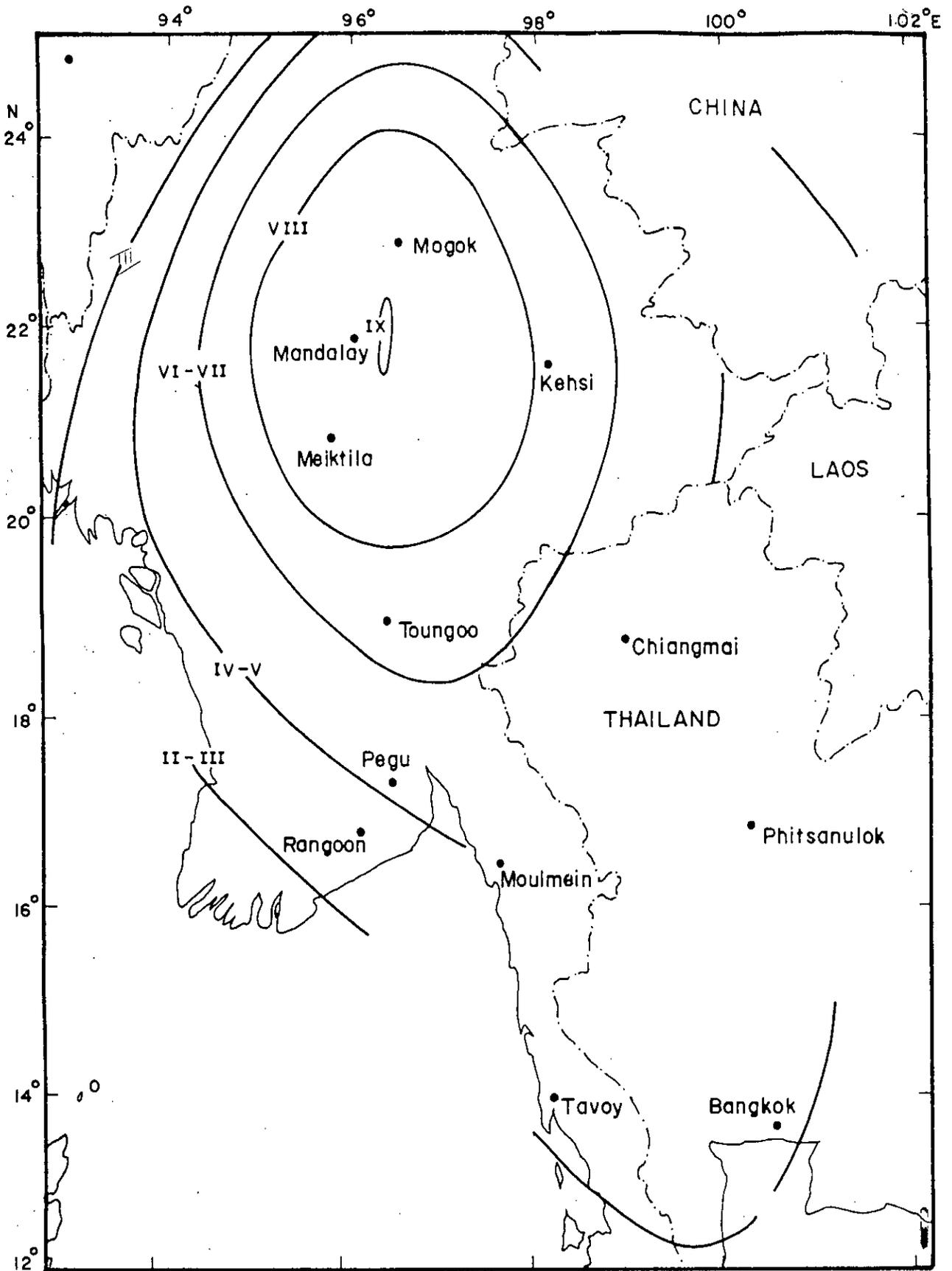


Fig. 5 Isoseismal Map of the Mandalay Earthquake of 23 May 1912 (after Brown, 1914)

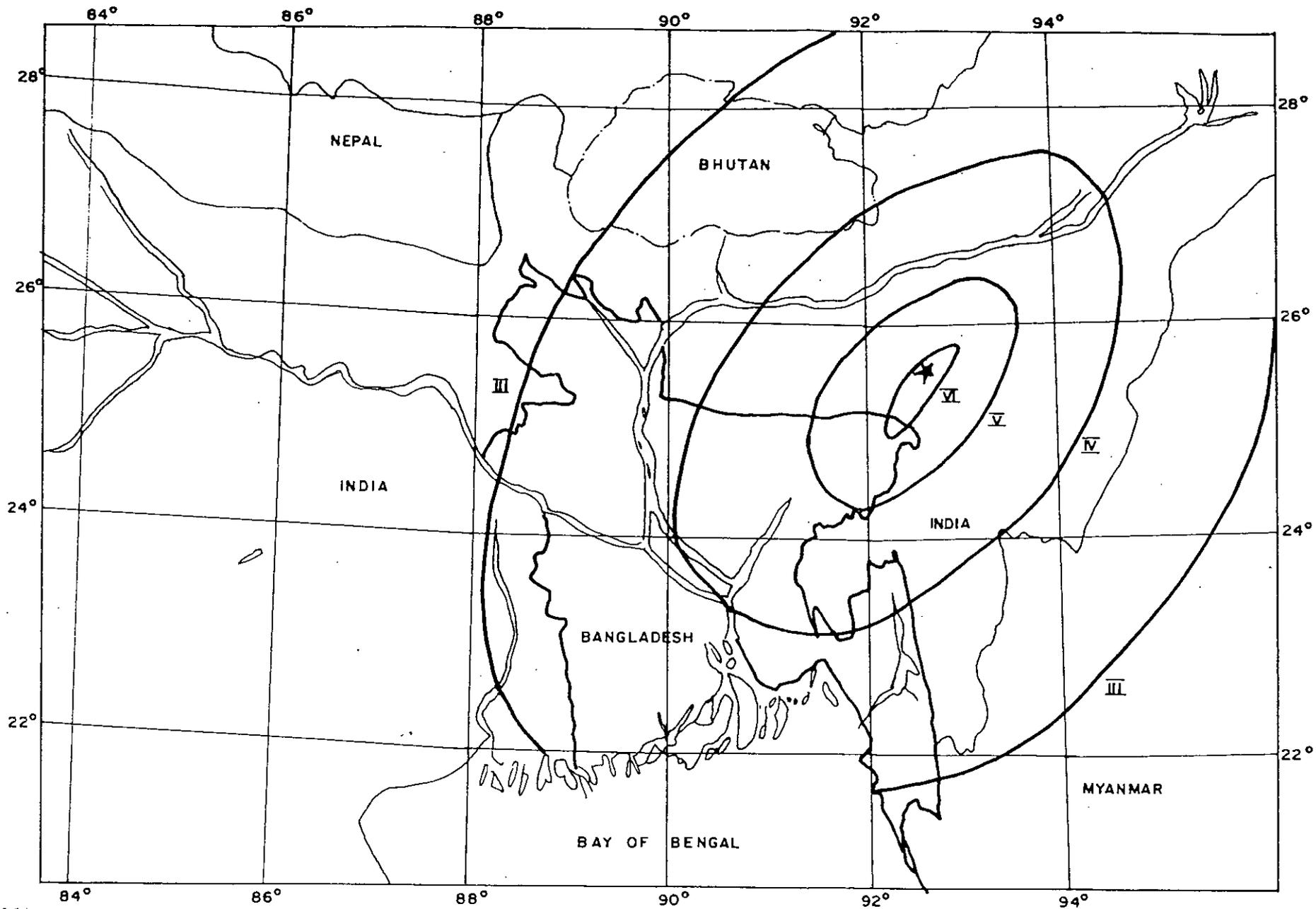


FIG. ISOSEISMAL MAP (IN TERMS OF EMS SCALE) OF THE MAIN SHOCK OF JULY 8, 1975 EARTHQUAKE. THE STAR SHOWS THE MACROSEISMIC EPICENTRE.

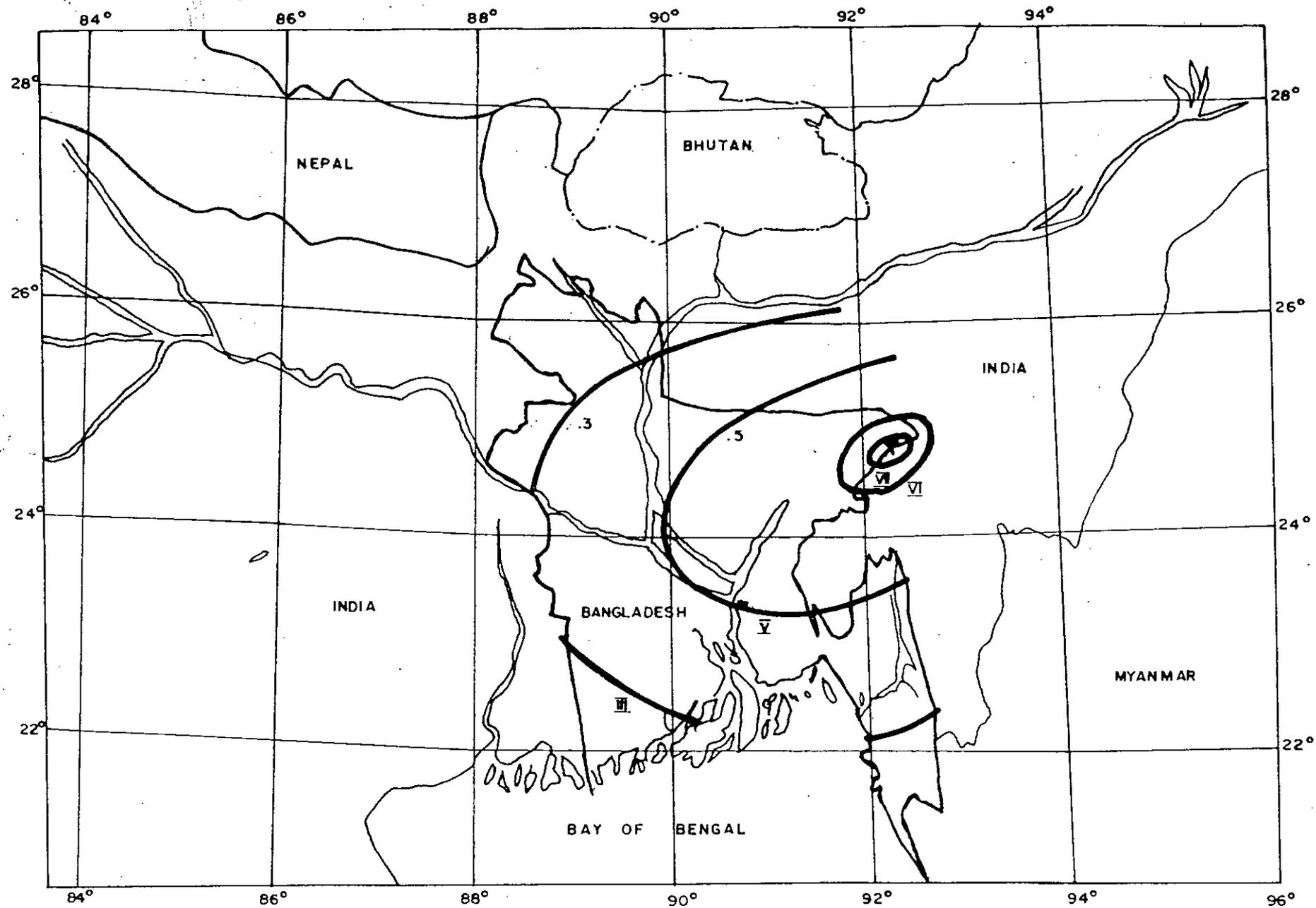


FIG. ISOSEISMAL MAP (IN TERMS OF EMS SCALE) OF THE MAIN SHOCK OF MAY 8, 1997 EARTHQUAKE. THE STAR SHOWS THE MACROSEISMIC EPICENTRE.

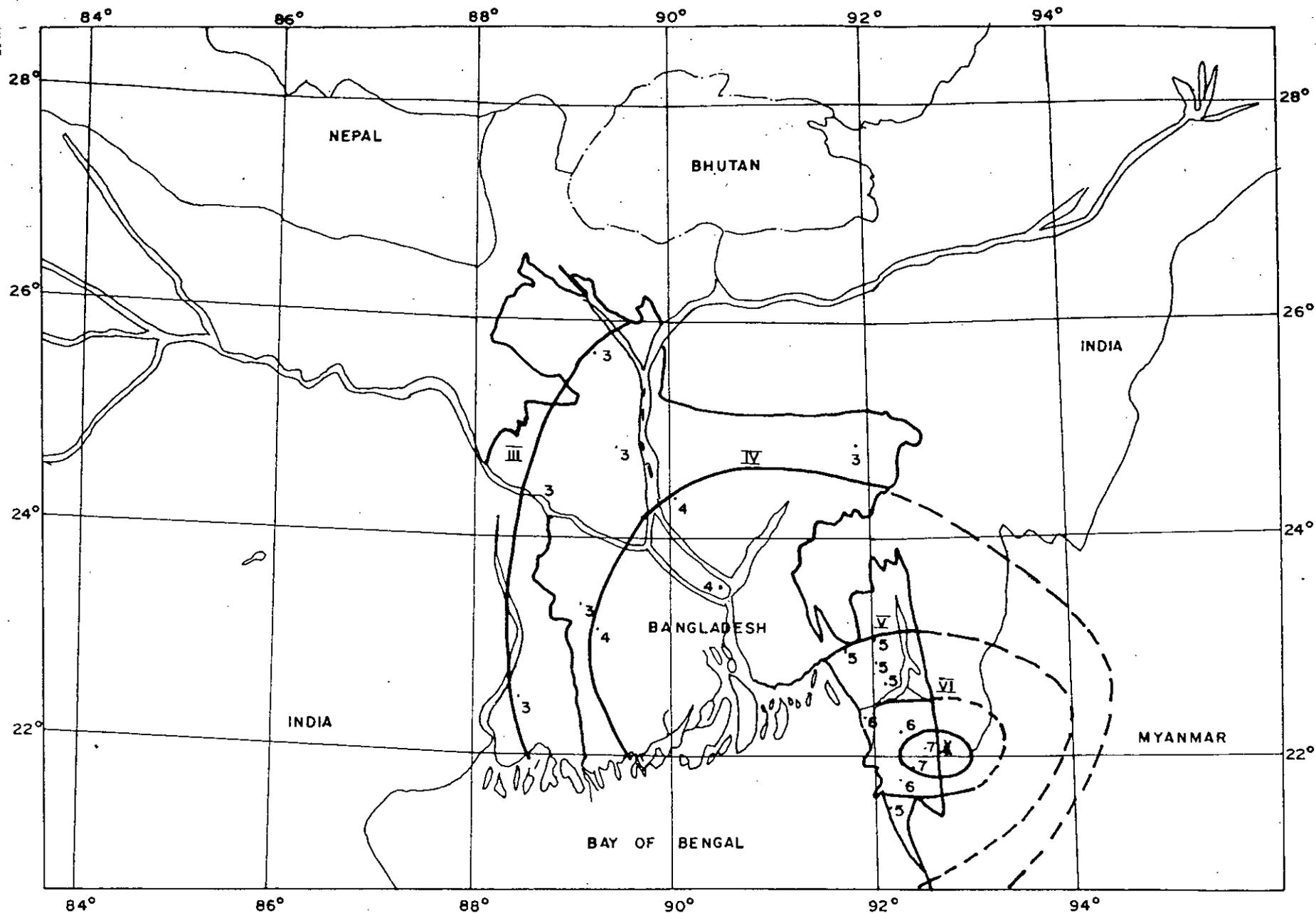
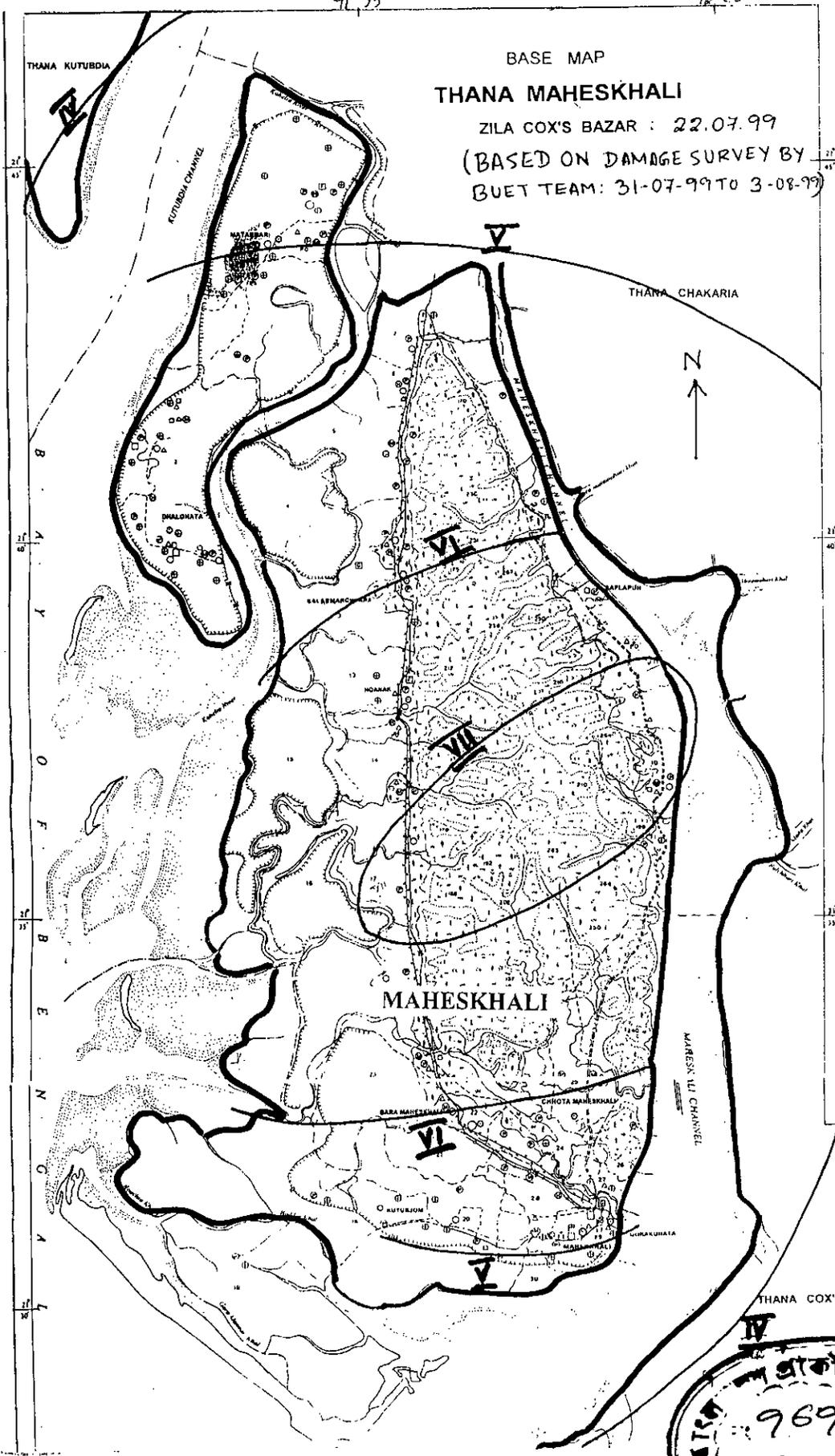


FIG. ISOSEISMAL MAP (IN TERMS OF EMS SCALE) OF THE MAIN SHOCK OF NOVEMBER 21, 1997 EARTHQUAKE. THE STAR SHOWS THE MACROSEISMIC EPICENTRE.

90° 55'

72° 50'



BASE MAP

THANA MAHESKHALI

ZILA COX'S BAZAR : 22.07.99

(BASED ON DAMAGE SURVEY BY

BUET TEAM: 31-07-99 TO 3-08-99)

THANA KUTUBDIA

THANA CHAKARIA

THANA COX'S BAZAR

