BANGLADESH

- SEISMICITY IN BANGLADESH

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1 INTRODUCTION

Bangladesh lies between 20°30' and 26°40' north latitude and 88°03' and 92°40' east longitude. It has an area of about 148,000 sq. km and a population of around 115 million.

Bangladesh is situated on one of the biggest deltas at the confluence of the second largest river system of the world, i.e., the Ganges-Brahmaputra-Meghna river system, which drains one of the heaviest rainfall areas in the world. Their total catchment area is approximately 1,544,000 sq. km, of which only 7.5% lies in Bangladesh.

Bangladesh is one of the most disaster-prone countries of the world. From 1960 to 1969, 18 disasters of varying magnitudes had been recorded in Bangladesh. From 1970 to 1979, the number of disasters that struck the country rose to 47 while from 1980 to 1989, the country had to confront nearly 77 disasters of varying intensities. The increasing trend is caused by the continuous increase in population, concentration of population in urban areas and active population migration to high risk areas.

Floods, cyclones and storm surges are the disasters that Bangladesh has to face recurrently. Disasters resulting from tornadoes, droughts, river erosion are also not rare. Table 1 highlights the vulnerability of Bangladesh to natural disasters. A review of the data shows that during recent decades, no severe earthquake has affected Bangladesh. In fact, the only major earthquake this century with epicenter in Bangladesh was in 1918. This has created a feeling of false security among the public and some decision-makers that earthquake is not a major hazard for Bangladesh. In fact, people seem to be preoccupied with floods, cyclones and storm surges and most of the government actions appear to be towards mitigation of these hazards.

Bangladesh has one of the highest rates of growth of urban population in the world. The current urban population is around 24 million (i.e., around 20% of the total population) and is expected to double in about 20 years. In 1981, there were 3 cities with population of more than 500,000 and 10 towns with population of more than 100,000. There are now 3 cities with population of more than 1 million.

Dhaka, the capital city, is one of the fastest growing cities in the world and its population has reached around 7.0 million. It is predicted that the population of the city would cross the 10 million mark around the beginning of the next century. By the year 2020, it is likely to become one of the most populous cities in the world with a population of more than 20 million. The sudden increase in the population and the necessity for commercial and office space as well as residential space in the capital city has resulted in the increasing number of tall buildings being built in the city. Government policy appears to encourage multistory housing but the preference appears to be for 5- to 6-story walk-up apartments.

TABLE 1: MAJOR NATURAL DISASTERS IN BANGLADESH

YEAR	TYPES OF DISASTER	DEATHS
1644-45	Floods	+
1648	Floods	+
1769-70	Drought	+
1783-84	Drought	+
1797	Cyclone	+
1822	Cyclone	40,000
1865-66	Drought in West Bengal, present Bangladesh largely escaped	135,000
*1869	Earthquake	+??
1873-74	Drought	+
1876	Cyclone	100,000
*1885	Earthquake	+??
1896-97	Drought	+
*1897	Earthquake	+??
1897	Cyclone	+
1898	Cyclone	175,000
1901	Cyclone	+
1906-07	Floods in East Bengal	+
1909	Cyclone (2)	+
1911	Cyclone	+
1917	Cyclone	+
*1918	Earthquake	+??
1919	Cyclone	+
1922	Cyclone	+
1923	Cyclone	+
*1934	Earthquake	+??
1941	Cyclone	+
1942	Cyclone	+
1943-44	Drought, irregular rain, transport dislocation and war, includes West Bengal	3,000,000
*1950	Earthquake	+??
1955	Floods	+
1960	Cyclone (2)	11,149
1961	Cyclone	11,468
1963	Cyclone	11,520
1964	Cyclone	196
1965	Cyclone	19,270
1966	Cyclone (2)	850
1969	Cyclone	75
1969	Tornado	922
1970	Cyclone	300,000
1972	Drought	+
1973	Cyclone (2)	103
1974	Cyclone	20
1974	Floods followed by famine	30,000
1975	Cyclone	5
1975	Floods	+
1977	Cyclone	+
1978-79	Drought	+
1981	Cyclone	2
1982	Drought	+
1983	Cyclone (2)	343
1984	Floods	+
1985	Cyclone	11,069
1986	Cyclone	14
1987	Floods	1,657
1988	Floods	2,379
1988	Cyclone	5,708
1989	Tornado	+??
1989	Drought	+
1991	Cyclone	138,868

Source: DCMU

+ : No data found

* : Earthquakes

Construction of tall buildings is a relatively new phenomenon in Bangladesh. The first 10-story building was completed in the early sixties. By 1971, when Bangladesh emerged as an independent country, there were only 9 buildings in the country with 9 or more stories. The tallest was only 40 meters (11-story). Recent years have witnessed a growing trend towards construction of 15- to 20-story buildings, almost all are situated in Dhaka. The tallest building (expected to be completed in 1993) is the 30-story Bangladesh Bank Building.

Most of the tall buildings are for commercial/office use. Out of the approximately 60 buildings (completed or under construction) with more than 9 stories, only about 10 are for residential use. Buildings with more than 5-6 stories are virtually nonexistent outside Dhaka. Only Chittagong, the second largest city and the major port, has 3 buildings with more than 9 stories. It is natural for most of the people with strong rural roots to prefer low-rise housing. Till recently most of the houses were single-story.

2 GEOLOGICAL AND SEISMOTECTONIC SETUP

Bangladesh is an alluvial plain with gentle slope towards the south and southeast, except in the eastern and extreme northeastern border regions where low, elongated hillocks of soft shale and sandstone of Tertiary age protrude through the alluvium.

The junction between the Platform and the Foredeep running southwest from Mymensingh to Calcutta (the Hinge line) is considered to be a zone of weakness; however, no association of the hinge with earthquakes has so far been established. The Foredeep is terminated in the northeast by a major fault, the Dauki fault at the southern margin of the Shillong Plateau. Some major earthquakes can be related to this fault. There are numerous faults particularly in the eastern part of the folded flank of the Foredeep. Here again there is no association with any major earthquake. Most recorded earthquakes had epicenters further east in Burma.

The eastern margin of the Indian plate is supposed to run through Myanmar, not far from the Bangladesh border, and northeast Assam (Arunachal Prodesh) is considered to be a corner of the northern and eastern margins of the plate.

The Himalayan arc can be regarded as one of the most intensely active seismic regions of the world. In northeast India the Shillong plateau and adjacent syntaxis between the two arcuate structures is one of the most unstable regions in the Alpine-Himalayan belt and faced three major earthquakes of magnitude greater than 8.0 within the last hundred years.

Northeast India can be broadly classified into four geotectonic units (Das, 1992), namely, (i) Arunachal Himalayas, (ii) Lohit Himalayas, (iii) Patkoi-Naga-Lushi-Arakan Yoma (Indo-Burma) hill ranges and (iv) Shillong Plateau-Assam basin. The region of Shillong Plateau-Assam basin has been identified as one of potential sites for severest earthquakes. Shillong massif and its northeasterly projected spur form the basement on which the alluvium and unfolded Tertiary formations of Assam basin have been deposited. It forms a wedge shaped triangular crustal block bounded by Arunachal Himalaya towards northwest, Lohit Himalaya towards northeast, the Indo-Burma folded belt towards southeast, the Bengal Burma basins on the south and Rajmahal-Garo-Sylhet gap towards the west. The contact of these geotectonic units with the Shillong plateau is marked by conspicuous thrust and tear faults. Two prominent tectonic features forming the boundary of Shillong plateau towards west and south are the Dhubri and Dauki tear faults, respectively. The plateau is bounded towards northwest by the Main Boundary Fault, towards northeast by Paleozoic and Precambrian formation of Mishmi and Lohit thrusts, towards southeast by Tertiary group of Naga thrust belts and on the south by Cambrian formation of Dauki tear fault, which merges towards east with the Haflong-Disang thrust zone. This complex tectonic regime surrounding Shillong Plateau reveals that the area has experienced great compressive stresses and resulting north-eastward drift of Indian plate along with westward overriding of Burmese plate.

At present, the southernmost thrusting in the Himalaya-Shillong Plateau region could be taking place along the southern fringe of the plateau coinciding with the Dauki fault. Currently, it is believed that the Shillong plateau has a thrust plane beneath it and is undergoing southward thrusting against a concept of vertical tectonism along the Dauki fault (Figure 1).

The Shillong plateau and its adjoining region including the northeastern part of Bangladesh have high seismic status. The seismic activity along the Dauki-Haflong fault zone is comparatively lower and a seismic gap has been postulated along this fault zone.

3 SEISMIC ZONING MAPS

The first seismic zoning map of the subcontinent was compiled by the Geological Survey of India in 1935 (Figure 2). Three zones were indicated in the maps, viz. *liable to severe damage, liable to moderate damage and liable to slight damage*. Areas which suffered moderate to severe damage in the past earthquakes with an intensity approximately higher than Rossi-Forel VII (MM VIII) within the first zone were also delineated. This qualitative map was based mainly on records of earthquake occurrence in the past. A major part of Bangladesh (in the north, northeast, and southeast) was shown under the "*liable to severe damage*".

In the sixties, the Meteorological Department prepared a zoning map, which was later adopted by the Bangladesh Meteorological Department (Figure 3). The country was divided into four zones, viz. major damage (seismic factor g/5 to g/10), moderate damage (g/10 to g/15), minor damage (g/15 to g/20) and negligible damage ($\leq$ g/20).

In the mid-seventies, when a number of large industrial complexes (e.g., fertilizer factory at Ashuganj) were being designed, the need for a more detailed investigation of seismic risk was felt. Public concern was heightened by the tremor felt in Chittagong City on May 12, 1977.

In June 1977, the government constituted a Committee of Experts to examine the problem and make appropriate recommendations. The terms of reference included preparing seismic zoning maps, preparing an outline of a building code for earthquake resistant design of structures, proposing means of educating the masses about the hazard and precautionary measures to minimize damage, and recommending facilities for observation, analysis and interpretation of relevant data.

The Committee, after reviewing all the available information, prepared a seismic zoning map (Figure 4). An outline of a code for earthquake resistant design was also prepared (Annex A).

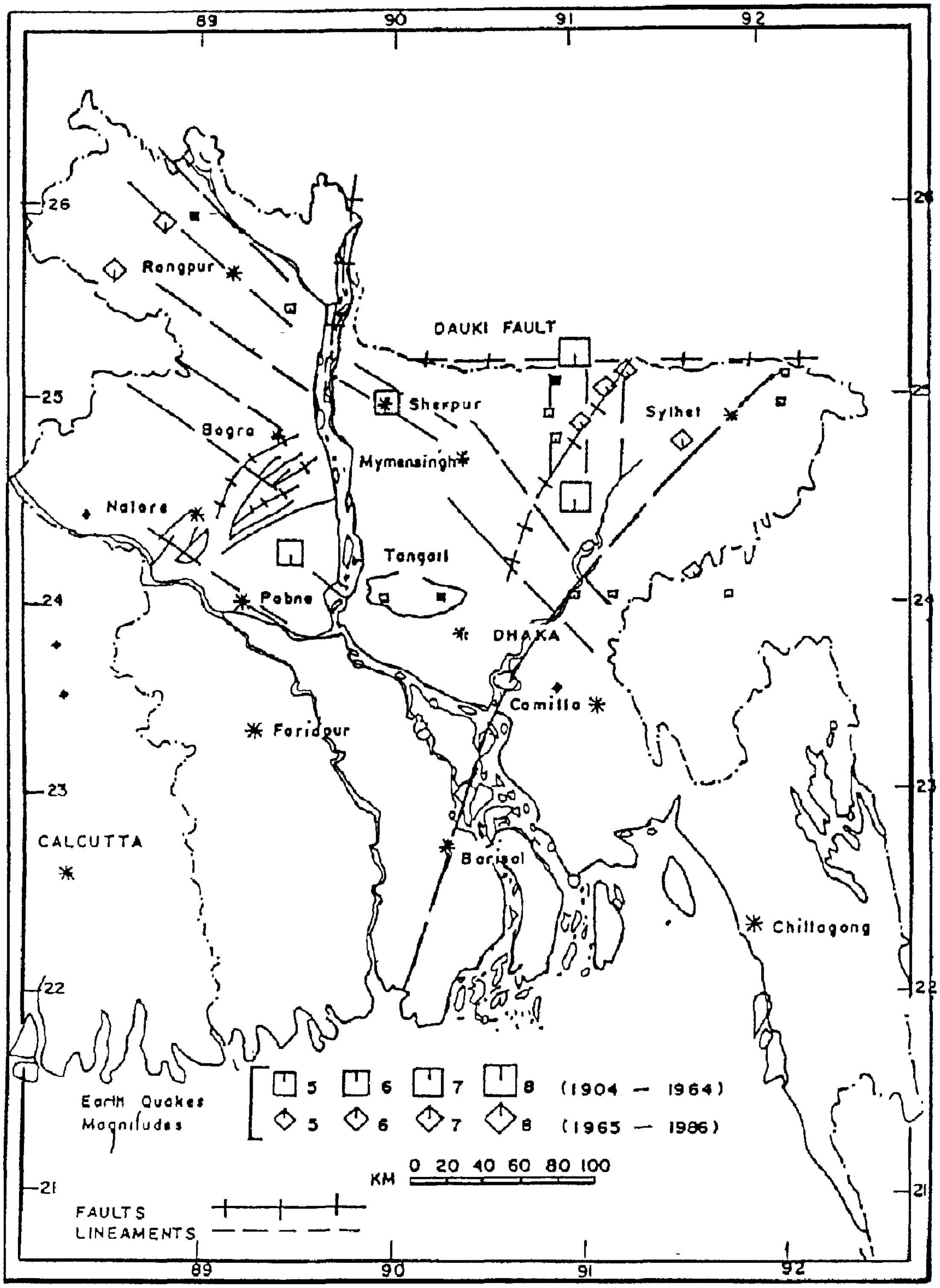


Figure 1: Seismotectonic lineaments capable of producing damaging earthquakes

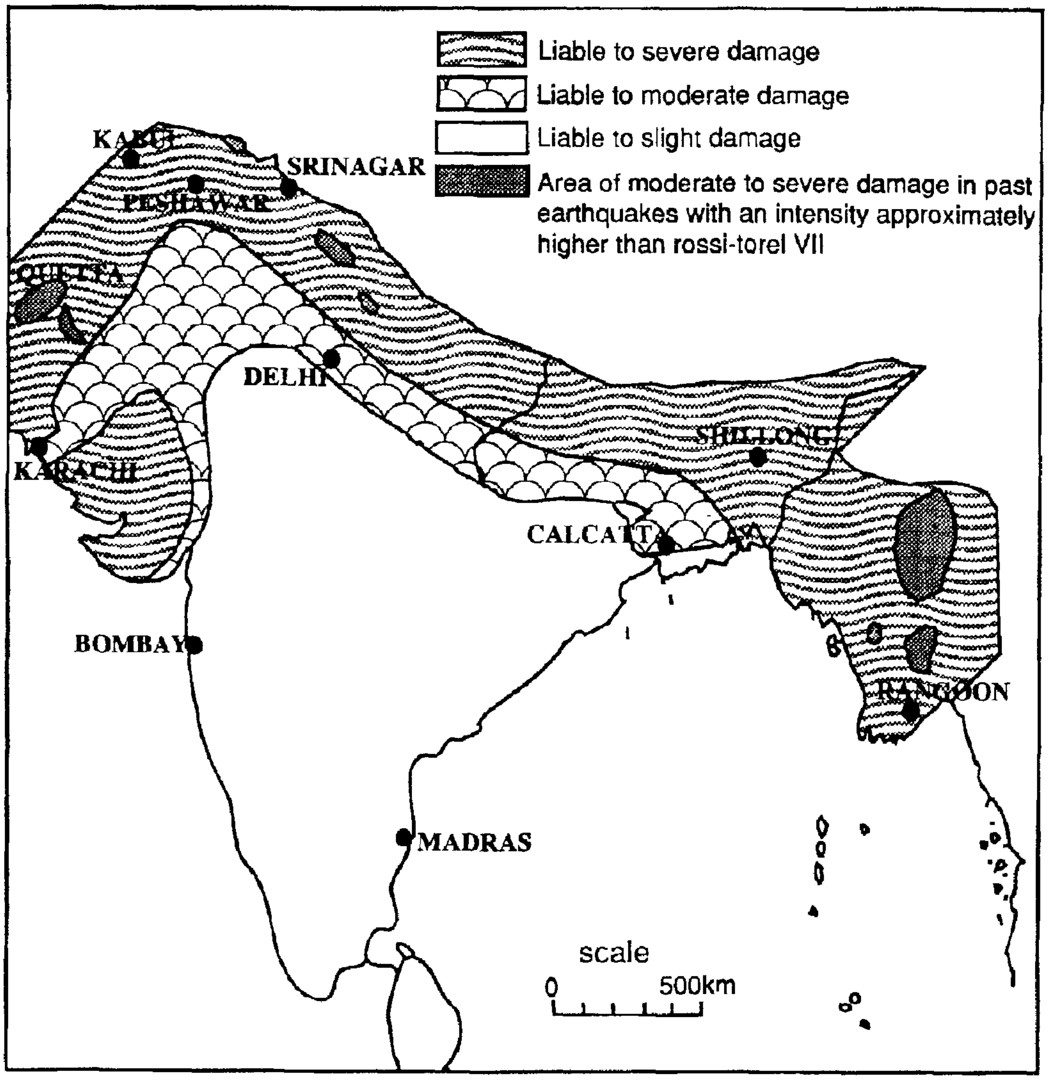
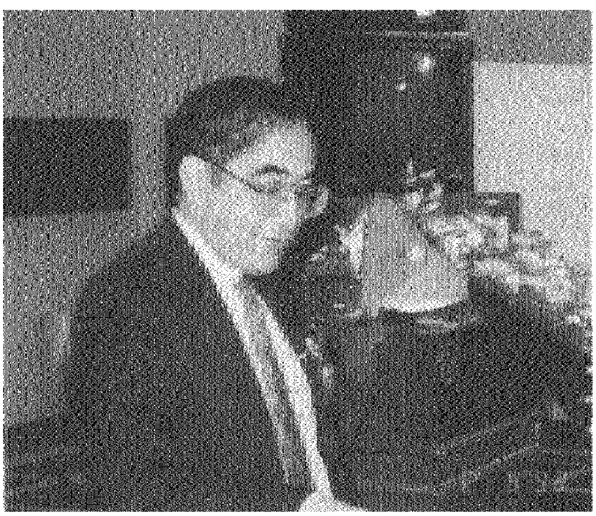


Figure 2: Seismic zones of Indian subcontinent compiled by the Geological Survey of India in 1935 (with additions up to 1950)



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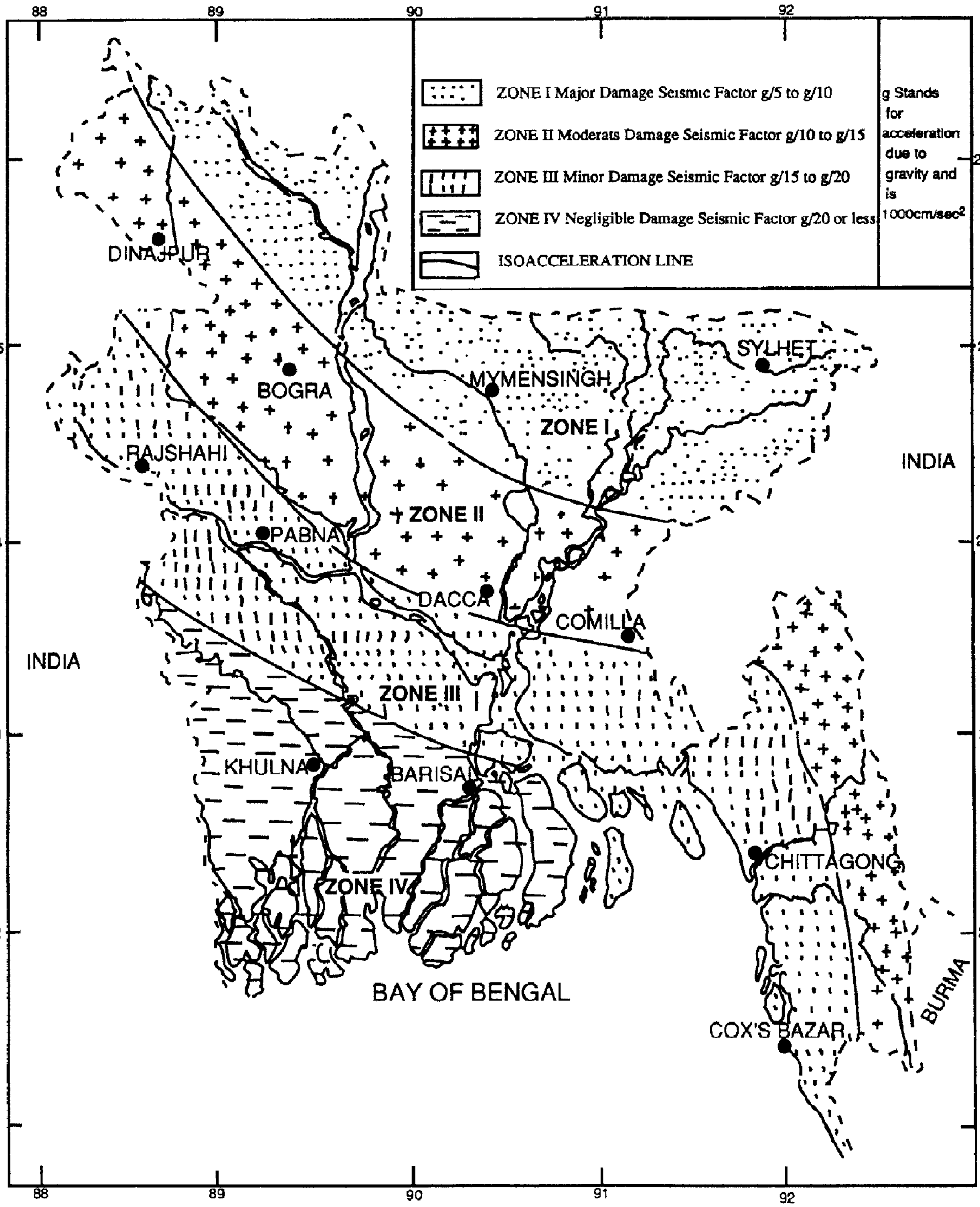


Figure 3: Seismic zones of Bangladesh (prepared by Bangladesh Meteorological Dept., 1972)

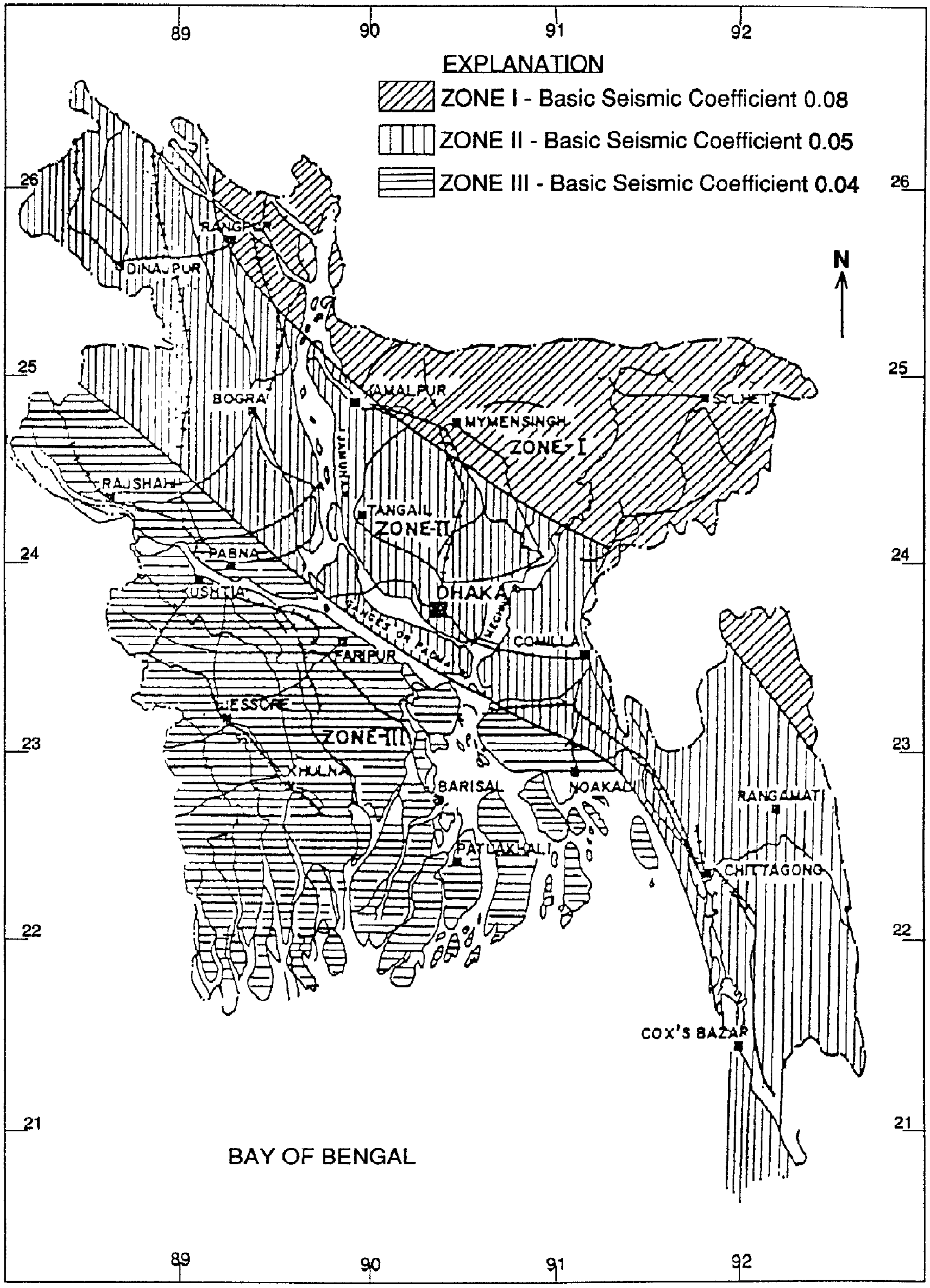


Figure 4: Seismic zoning map of Bangladesh (Source: GSB, 1979)

3.1 Major Earthquakes Affecting Bangladesh

During the last 150 years, 7 earthquakes (with magnitude ≥ 7) have affected Bangladesh (Table 2). Out of these, only two (viz. 1885 and 1918) had their epicenters within Bangladesh. These earthquakes and their effects are outlined below:

TABLE 2: MAJOR EARTHQUAKES THAT AFFECTED BANGLADESH

Date	Name of Earthquake	Magnitude	Epicentral Distance from Dhaka (km)
January 10, 1869	Cachar Earthquake	7.5	250
July 14, 1885	Bengal Earthquake	7.0	170
June 12, 1897	Great Indian Earthquake	8.7	230
July 8, 1918	Srimangal Earthquake	7.6	150
July 2, 1930	Dhubri Earthquake	7.1	250
January 15, 1934	Bihar-Nepal Earthquake	8.3	510
August 15, 1950	Assam Earthquake	8.5	780

The Cachar Earthquake of January 10, 1869 with epicenter in the northern border of Jaintia Hills of Assam caused great damage in the Manipur and Cachar district of Assam. In Bangladesh, major damage occurred only in the eastern parts of the Sylhet district but the tremor was felt all over the country. The magnitude is estimated to be 7.5 on the Richter scale.

The Bengal Earthquake of July 14, 1885 caused considerable damage in Sirajganj-Bogra region and perhaps severer damage in Jamalpur-Sherpur-Mymensingh region (Figure 5). The magnitude is estimated as 7.0 on the Richter scale. The design of a major bridge near Sirajganj has led to a thorough analysis of this earthquake by Bolt (1987). He concluded that the epicenter was perhaps near the Bogra fault system (24.80°N, 89.50°E) and not near Manikganj (23°59'N, 90°6'E) as originally determined by Middlemeiss (1885).

The Great Earthquake of June 12, 1897 of magnitude 8.7 on the Richter scale with the epicentral area in the central part of the Shillong plateau was one of the greatest earthquakes and in Bangladesh was perhaps the cause of greatest and most widespread earthquake damage. Damage was very severe in Sylhet, northern Mymensingh and eastern Rangpur. Minor damage occurred practically throughout the country (Figure 6).

The Srimangal Earthquake of July 8, 1918 of magnitude 7.6 had its epicenter in Balisera Valley very near Srimangal. Intense damage occurred in Srimangal. However, due to the shallow focal depth, the intensity rapidly decreased. In Dhaka, only minor effects were observed (Figure 7).

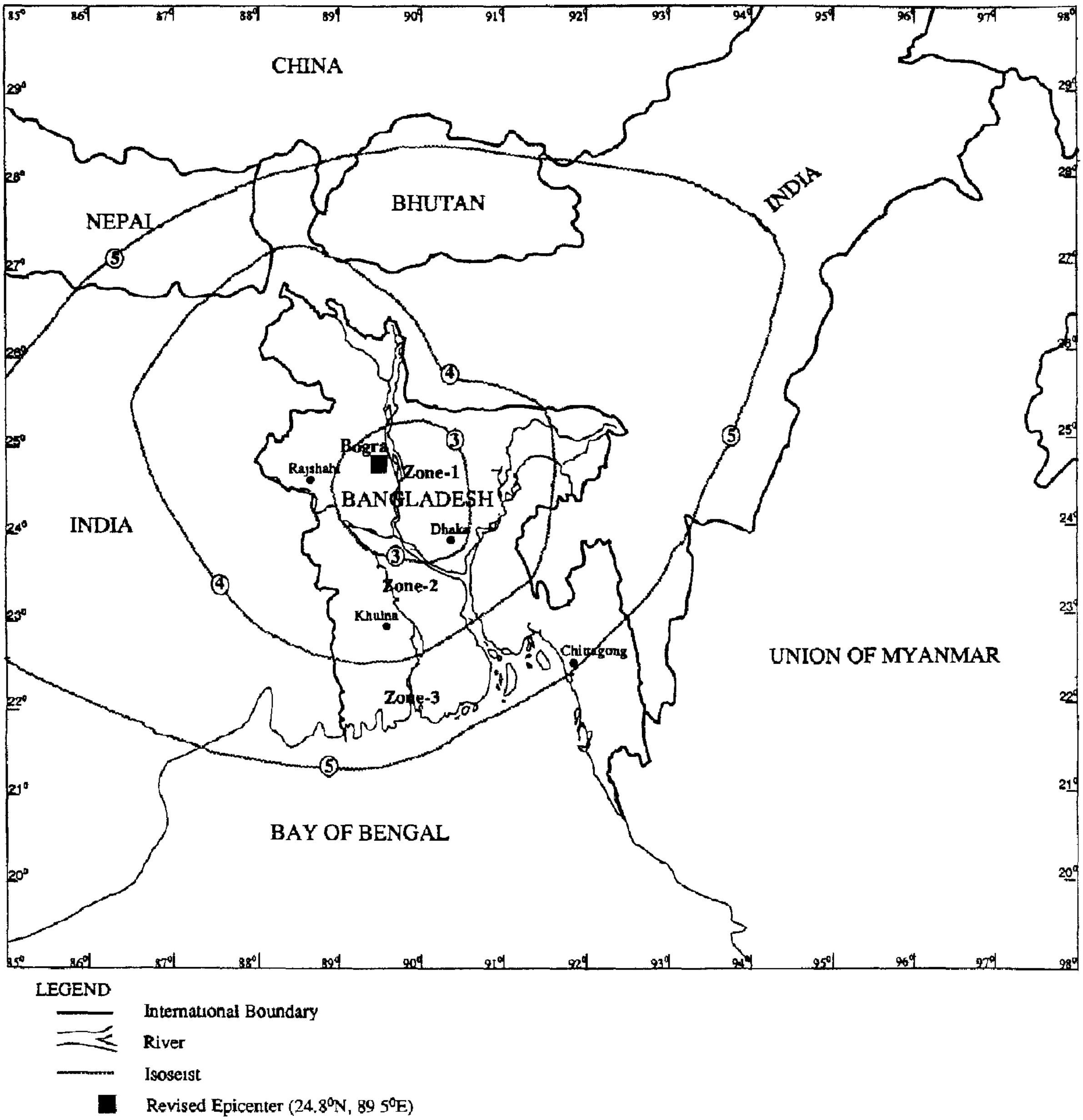


Figure 5: Isoseismals of Bengal earthquake of July 14, 1885

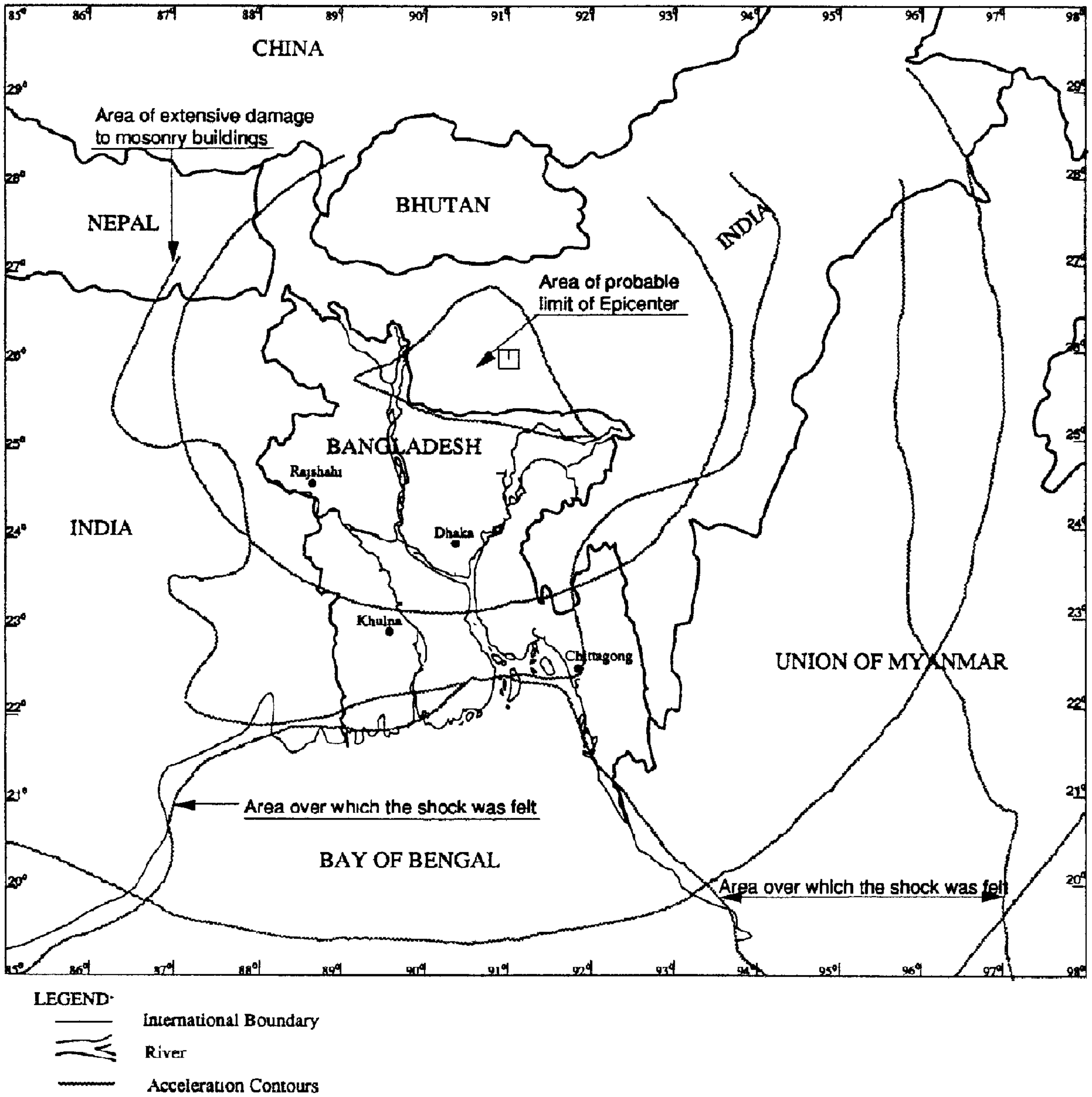


Figure 6: Isoseismals of Great Assam earthquake of June 12, 1897

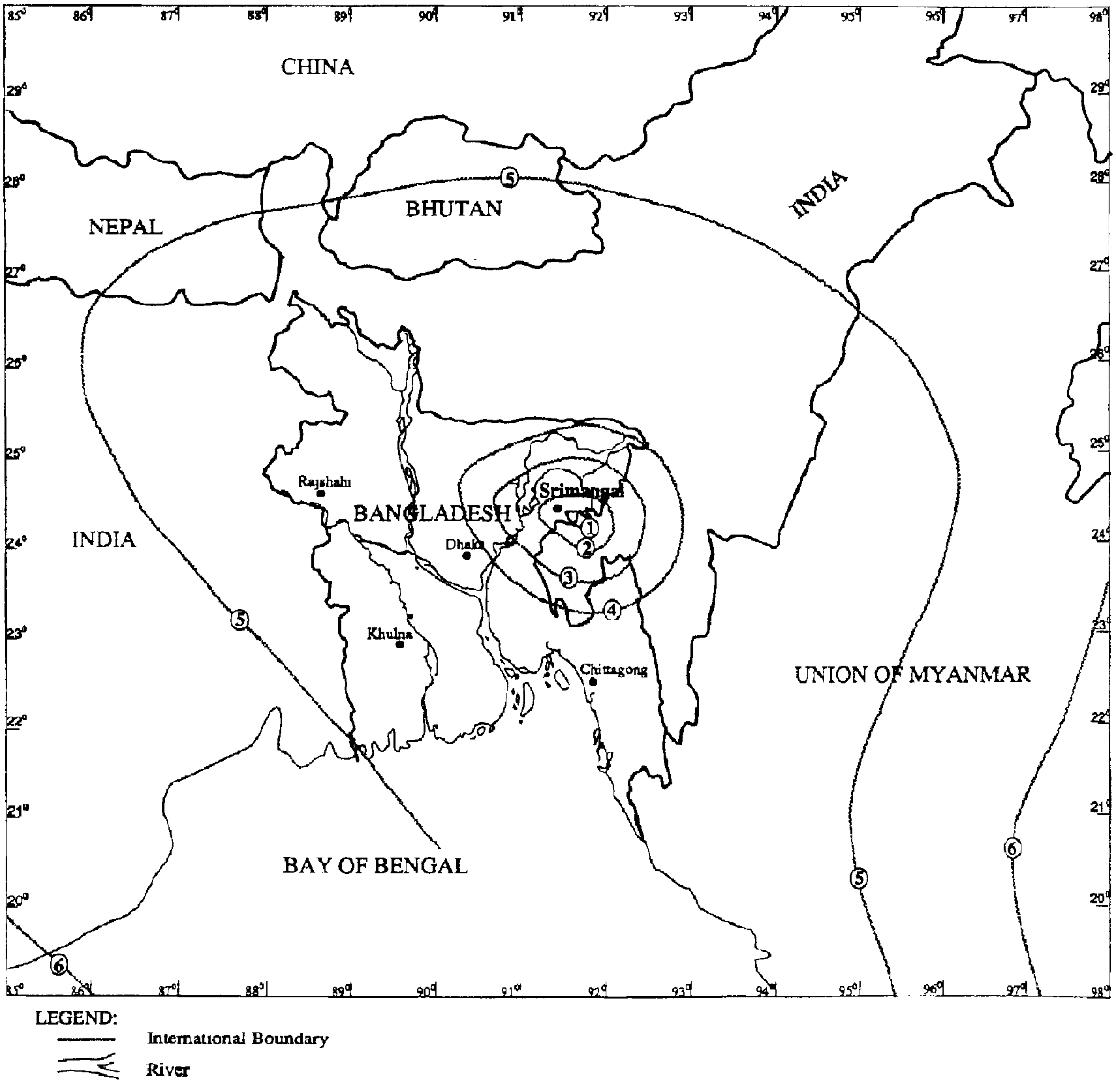


Figure 7: Isoseismals of Srimangal earthquake of July 8, 1918

The Dhubri Earthquake of July 3, 1930 with a magnitude of 7.1 on the Richter scale had its epicenter near Dhubri town of Assam. It caused major damage only in the eastern parts of Rangpur district.

The Bihar Earthquake of January 15, 1934 of magnitude 8.3 and with epicenter north of Darbhanga caused great damage in Bihar, Nepal and Uttar Pradesh but did not affect any part of Bangladesh with any degree of severity (Figure 8).

The Assam Earthquake of August 15, 1950 was again one of the severest earthquakes of the world. Its epicenter was in the Arunachal Pradesh, northeast of Assam. The tremor was felt throughout Bangladesh but no damage was reported anywhere. The magnitude was 8.5 on the Richter scale.

A list of earthquakes along with their epicenters and magnitudes is presented in Annex B. Figure 9 shows a map of the locations of epicenters of these earthquakes. Figures 9a-9e show the distribution of epicenters categorized by magnitudes.

Bolt (1987) analyzed the different seismic sources in and around Bangladesh and arrived at conclusions related to maximum likely earthquake magnitude. The magnitudes of earthquake suggested by Bolt (1987) in Table 3 are the maximum magnitude generated in these tectonic blocks as recorded in the historical seismic catalogue. The historical seismic catalogue of the region covers approximately 250 years of recent seismicity of the region and such a meager data base does not provide a true picture of the seismicity of the tectonic provinces. For example, the Assam and the Tripura fault zones contain significant faults capable of producing magnitude 8.6 and 8.0 earthquakes, respectively, in the future. Similarly, earthquakes with maximum magnitude of 7.5 in Sub-Dauki fault zone and in Boga fault zone are not unlikely events. After a thorough review of available data, Ali and Choudhury (1992) recommended magnitudes of Operational Basis Earthquakes and Maximum Credible Earthquakes (Table 4). The focal depths of earthquakes are also given in this table.

TABLE 3: SIGNIFICANT SEISMIC SOURCES FOR EARTHQUAKE HAZARD IN BANGLADESH

Location	Maximum likely earthquake magnitude
A. Assam fault zone	8.0
B. Tripura fault zone	7.0
C. Sub-Dauki fault zone	7.3
D. Bogra fault zone	7.0

Source: Bolt, B.A. (1987)

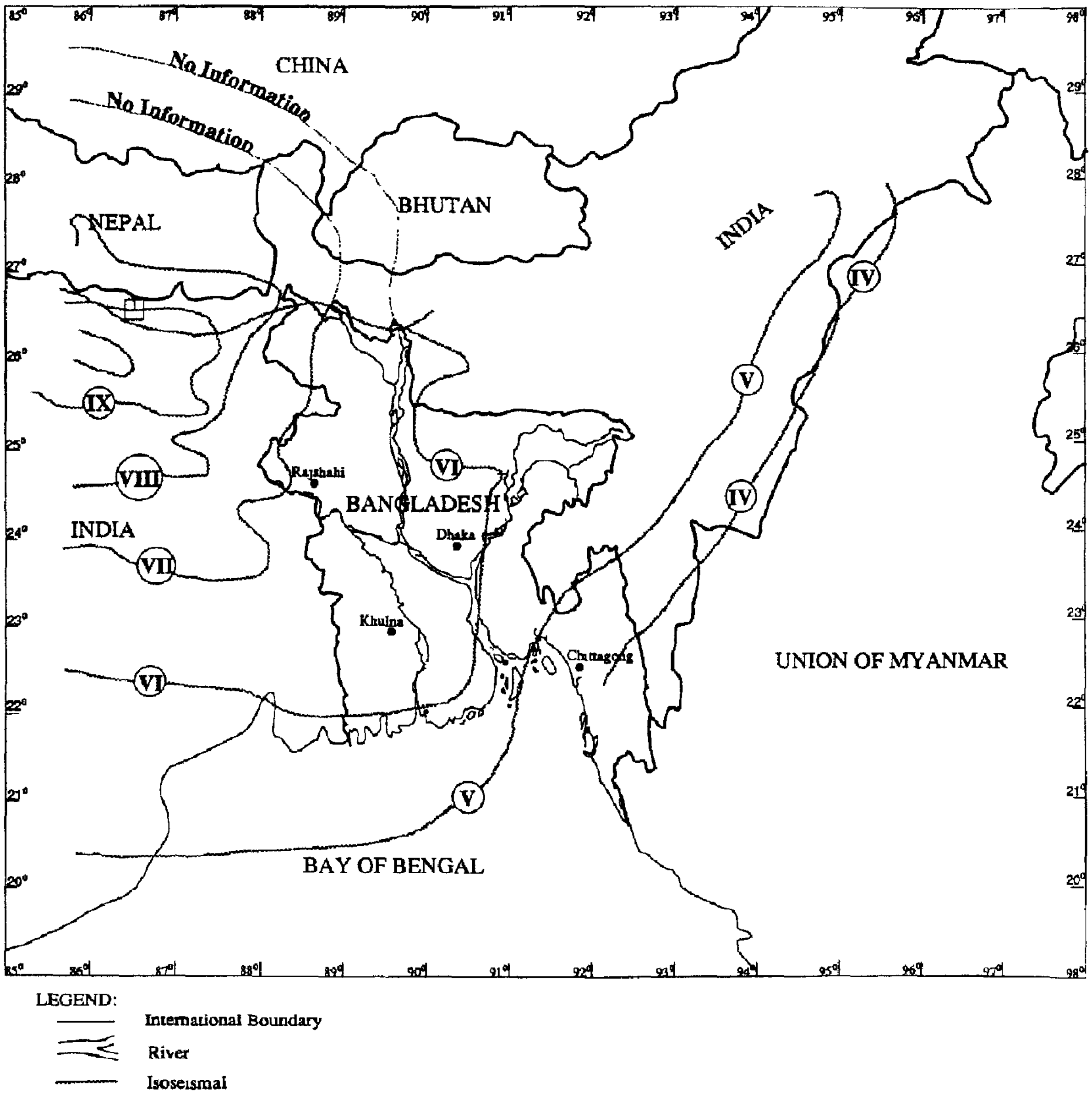
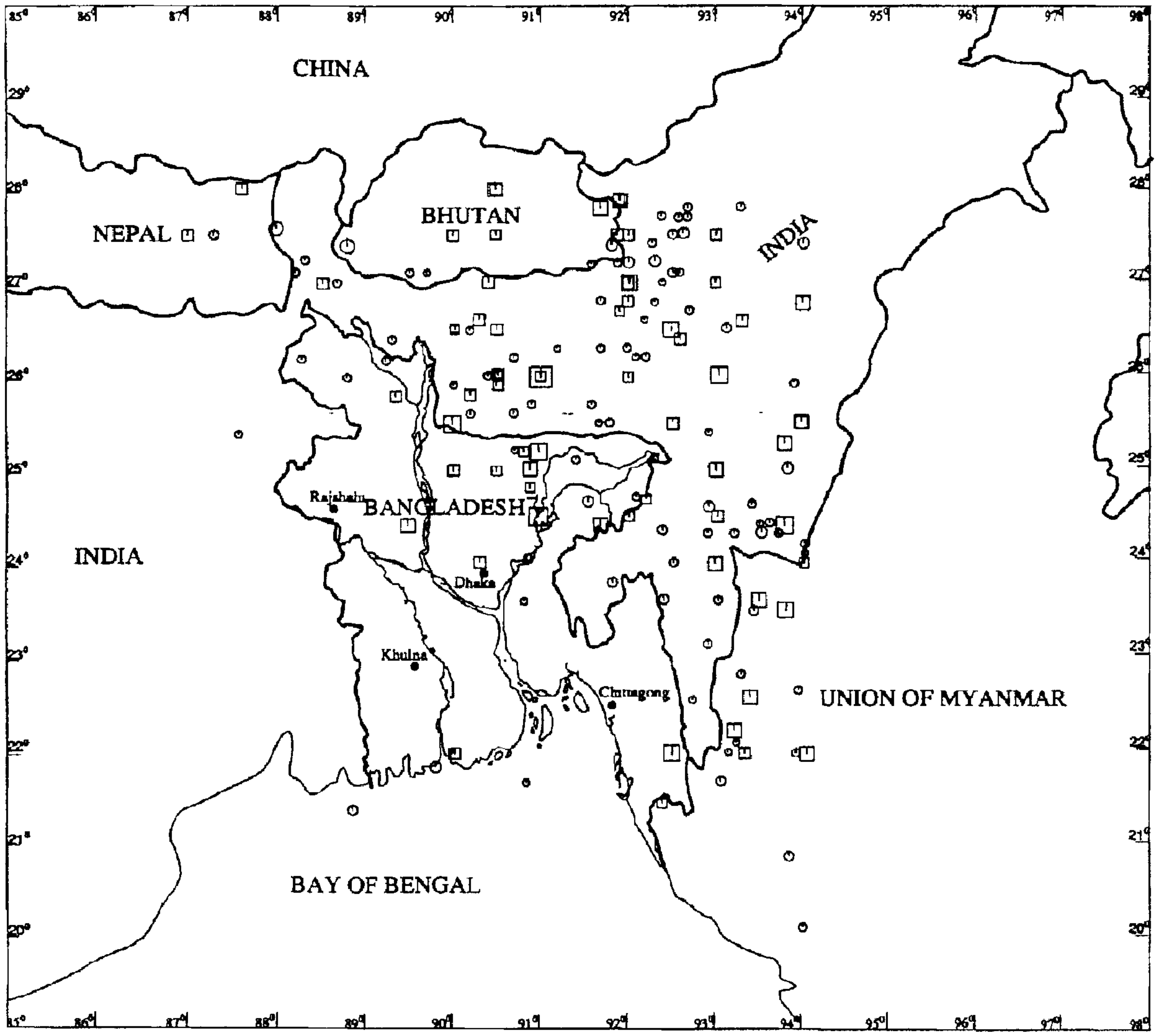


Figure 8: Isoseismals of Bihar-Nepal earthquake of January 15, 1934



DATA FROM:

1. Catalogue of Earthquakes in India and Neighbourhood, 1983
2. Bulletin of the Indian Society of Earthquake Technology, 1988-1990

LEGEND:

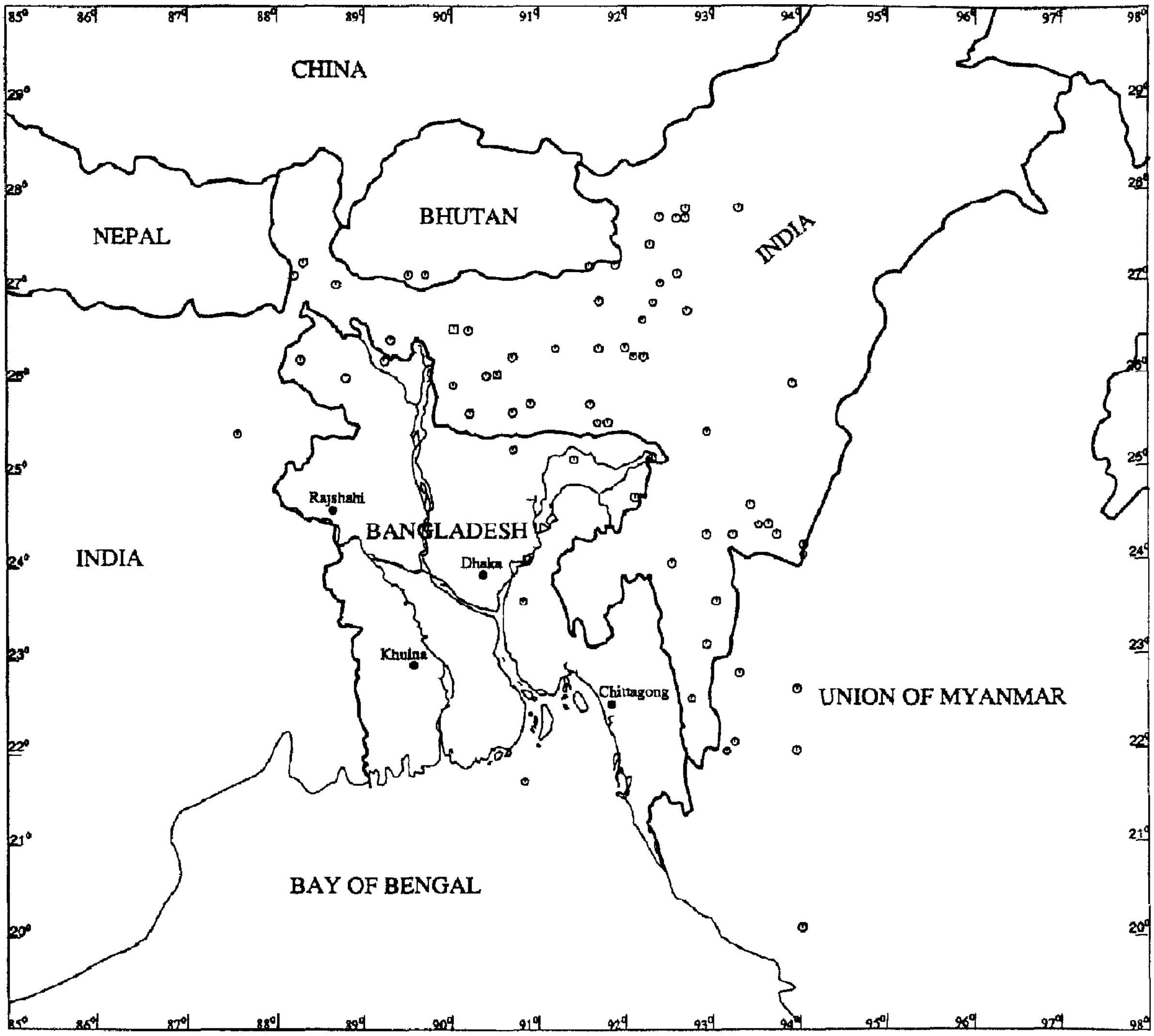
International Boundary

River

Symbol	Magnitude
	4.0< Mag ≤4.4
	4.5< Mag ≤4.9
	5.0< Mag ≤5.4
	5.5< Mag ≤5.9
	6.0< Mag ≤6.4
	6.5< Mag ≤6.9
	7.0< Mag ≤7.4
	7.5< Mag ≤7.9
	8.0< Mag ≤8.4
	8.5< Mag ≤8.9

(□ = M (1897-1962), ○ = Mb (1963-1990))

Figure 9: Seismic map showing epicentres in Bangladesh and neighbourhood



DATA FROM:
1. Catalogue of Earthquakes in India and Neighbourhood, 1983
2. Bulletin of the Indian Society of Earthquake Technology, 1988-1990

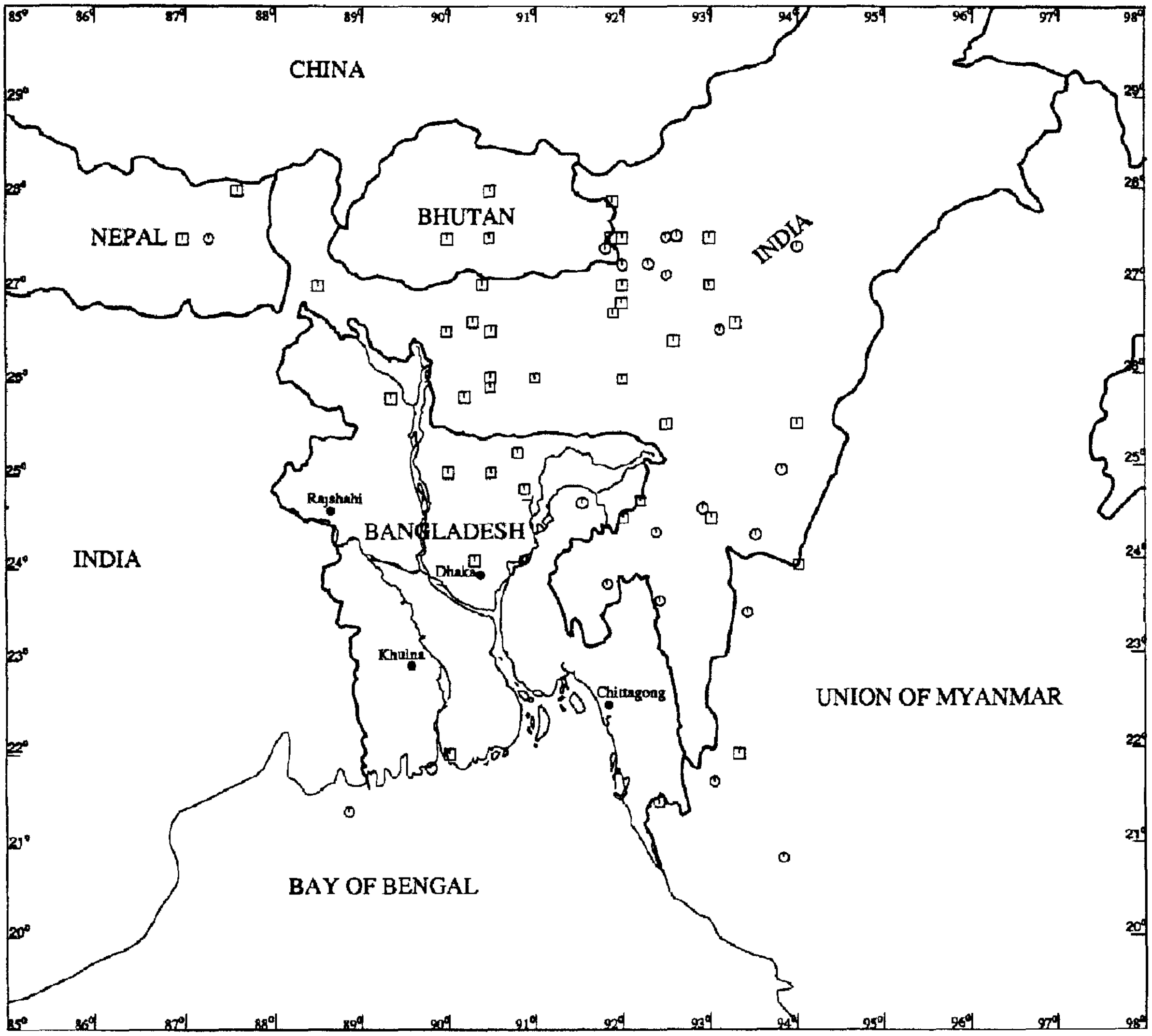
LEGEND:

International Boundary

River

Symbol	Magnitude
	4.0< Mag ≤4.4
	4.5< Mag ≤4.9 (□ = M (1897-1962), ○ = Mb (1963-1990))

Figure 9a: Seismic map showing epicentres in Bangladesh and neighbourhood, for 4.0<Mag≤4.9



DATA FROM:

1. Catalogue of Earthquakes in India and Neighbourhood, 1983
2. Bulletin of the Indian Society of Earthquake Technology, 1988-1990

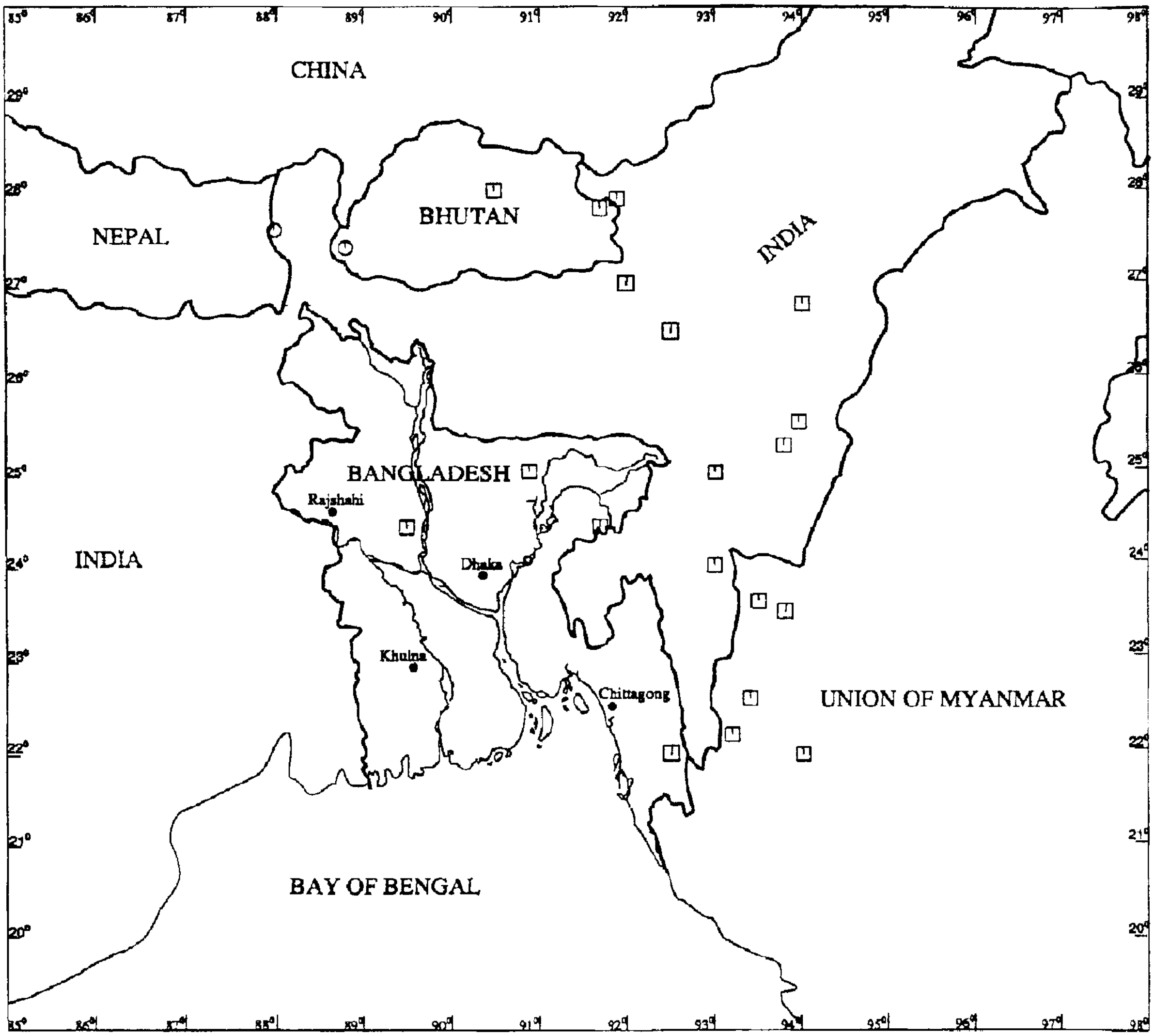
LEGEND:

International Boundary

River

Symbol	Magnitude
□ ○	5.0< Mag ≤5.4
□ ○	5.5< Mag ≤5.9 (□ = M (1897-1962), ○ = Mb (1963-1990))

Figure 9b: Seismic map showing epicentres in Bangladesh and neighbourhood, for 5.0<Mag≤5.9



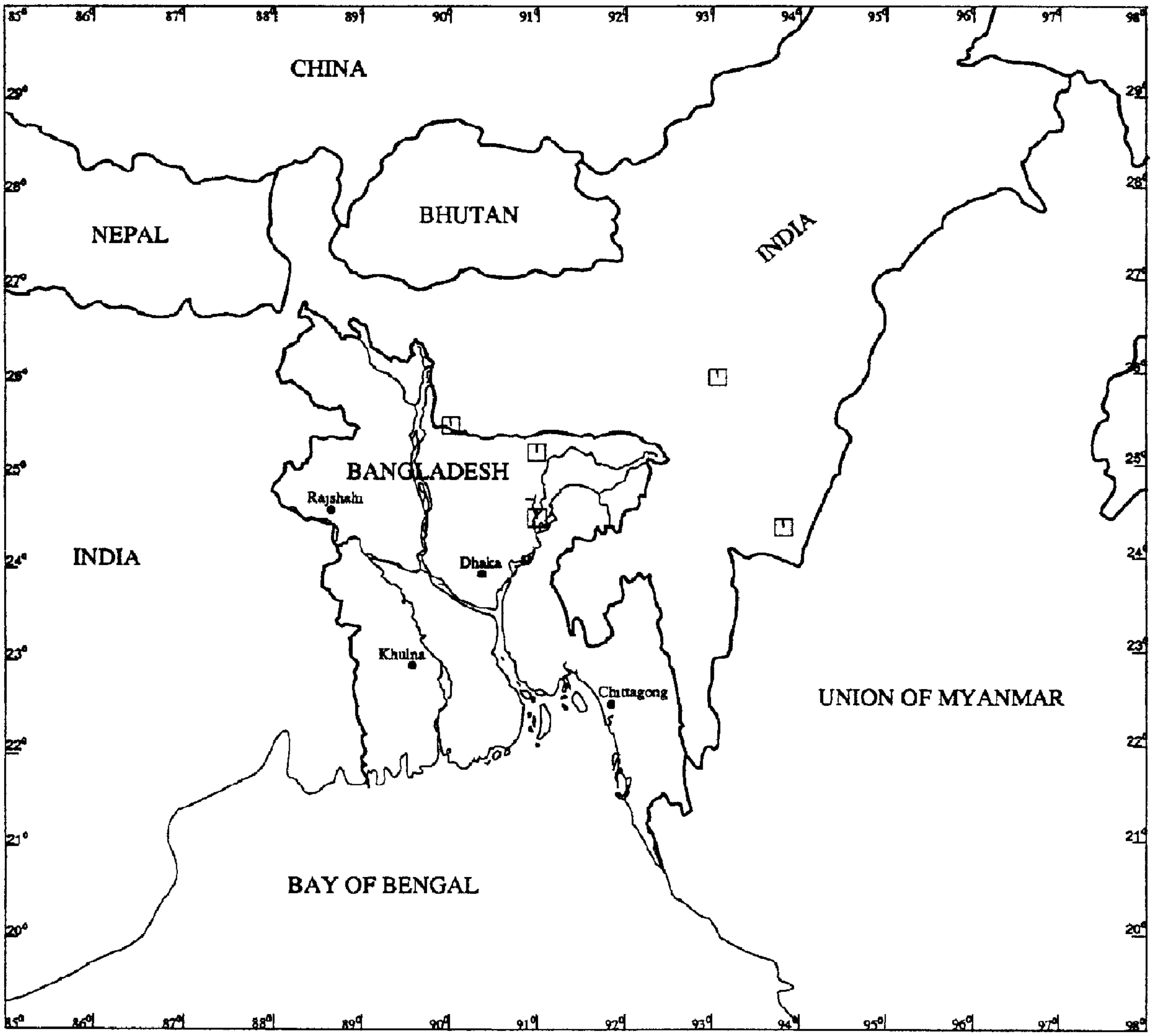
DATA FROM:

1. Catalogue of Earthquakes in India and Neighbourhood, 1983
2. Bulletin of the Indian Society of Earthquake Technology, 1988-1990

LEGEND.

———	International Boundary
(river symbol)	River
Symbol	Magnitude
□ ○	6.0< Mag ≤6.4
□ ○	6.5< Mag ≤6.9 (□ = M (1897-1962), ○ = Mb (1963-1990))

Figure 9c: Seismic map showing epicentres in Bangladesh and neighbourhood, for 6.0<Mag≤6.9



DATA FROM.
1. Catalogue of Earthquakes in India and Neighbourhood, 1983
2. Bulletin of the Indian Society of Earthquake Technology, 1988-1990

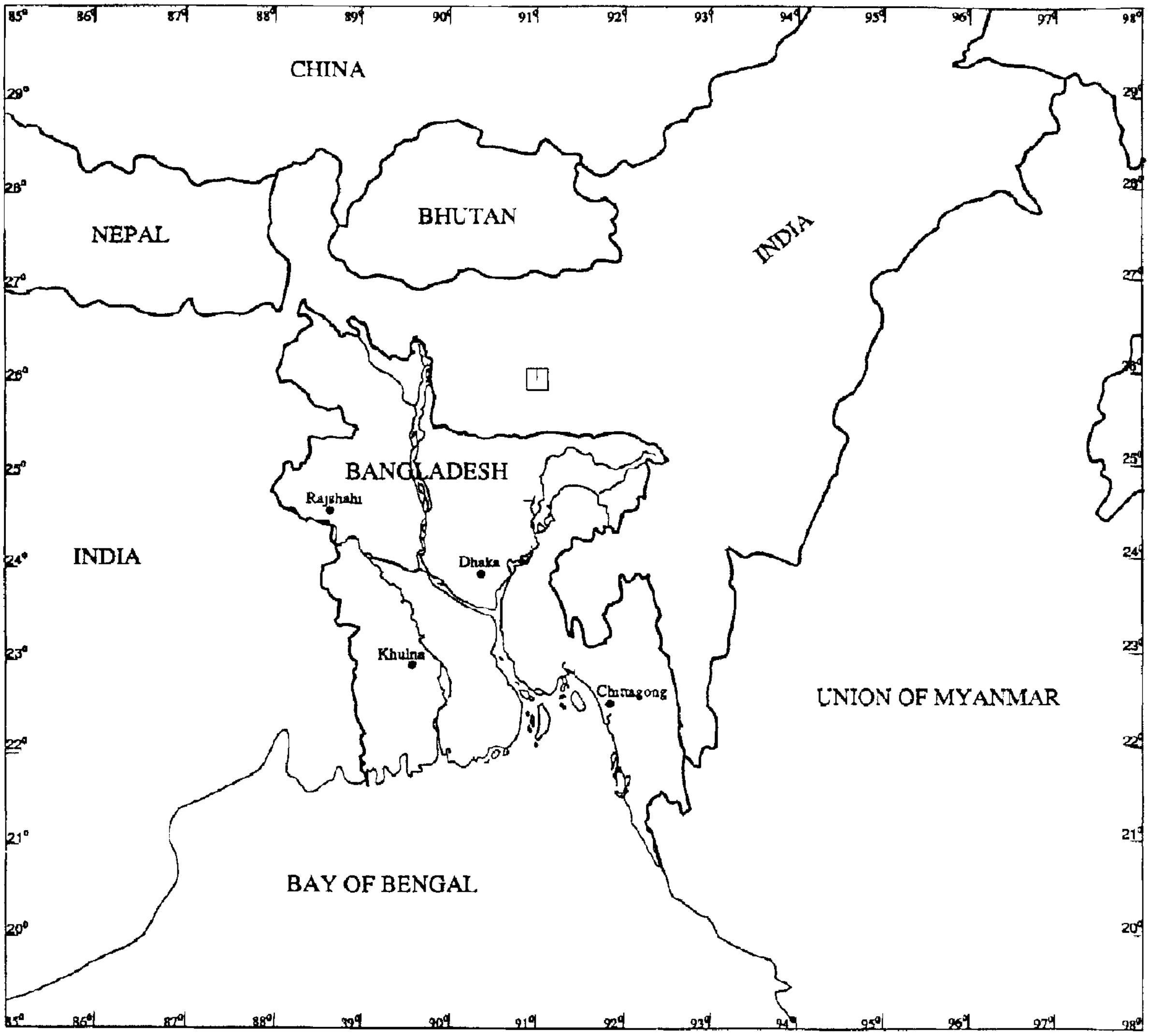
LEGEND:

International Boundary

River

Symbol	Magnitude
□ ⊙	7.0< Mag ≤7.4
□ ⊙	7.5< Mag ≤7.9 (□ = M (1897-1962), ⊙ = Mb (1963-1990))

Figure 9d: Seismic map showing epicentres in Bangladesh and neighbourhood, for 7.0<Mag≤7.9



DATA FROM
1. Catalogue of Earthquakes in India and Neighbourhood, 1983
2. Bulletin of the Indian Society of Earthquake Technology, 1988-1990

LEGEND:
International Boundary
River

Symbol	Magnitude
□ ○	8.0< Mag ≤8.4
□ ○	8.5< Mag ≤8.9

(□ = M (1897-1962), ○ = Mb (1963-1990))

Figure 9e: Seismic map showing epicentres in Bangladesh and neighbourhood, for 8.0<Mag≤8.9

TABLE 4: TECTONIC PROVINCES AND THEIR EARTHQUAKE POTENTIAL

Location	Operating Basis Magnitude (Richter)	Maximum Credible Magnitude (Richter)	Depth of focus (km)
A. Assam fault zone	8.0	8.7	0-70
B. Tripura fault zone	7.0	8.0	0-70
C. Sub-Dauki fault zone	7.3	7.5	0-70
D. Bogra fault zone	7.0	7.5	0-70

Source: Ali and Choudhury (1992)

3.2 Magnitude-Frequency Relationship

Design magnitudes of earthquakes are estimated using the magnitude frequency relationship:

$$Log_{10}N = a - bM$$

where
N = Cumulative number of earthquakes with magnitude equal to or larger than M
M = Magnitude of earthquake and
a, b = regression coefficients.

Using historical data, design magnitudes of earthquakes for return periods of 50, 100 and 200 years have been estimated by Kundu (1992) and are shown in Table 5. The areal distribution of epicenters of earthquakes was considered. He performed the analysis by grouping the data into three categories bounded by latitude and longitude lines shown in the table. In determining the magnitude frequency relationship, earthquake magnitudes before 1963 have been assumed to be Richter Magnitude and have been converted to body wave magnitudes using the relationship:

$$M_b = 1.7 + 0.8M - 0.01M^2$$

TABLE 5: MAGNITUDE-FREQUENCY RELATIONSHIP FOR THREE GROUPS

Group	Area Covered	Obs. Period	Reg. Eqn. for M	Reg. Eqn. for M_b
A	Lat 21°-27° Long. 88°-93°	1897-1962 1963-1991 1897-1991	$\log_{10}N = 3.868 - 0.454M$	$\log_{10}N = 5.24 - 0.666M_b$ $\log_{10}N = 6.63 - 1.046M_b$ $\log_{10}N = 5.00 - 0.621M_b$
B	Lat. 20°-28° Long. 87°-94°	1897-1962 1963-1991 1897-1991	$\log_{10}N = 4.459 - 0.52M$	$\log_{10}N = 5.85 - 0.738M_b$ $\log_{10}N = 6.58 - 0.951M_b$ $\log_{10}N = 5.68 - 0.700M_b$
C	Lat. 21°-28° Long. 87°-93°	1897-1962 1963-1991 1897-1991	$\log_{10}N = 4.223 - 0.499M$	$\log_{10}N = 5.59 - 0.711M_b$ $\log_{10}N = 6.24 - 0.913M_b$ $\log_{10}N = 5.42 - 0.674M_b$

Source: Kundu (1992)

N = cumulative number of earthquakes equal to or larger than a given value of body-wave magnitude (M_b) or Richter scale magnitude (M)

3.3 Ground Motion Parameters

One of the major difficulties in determining ground motion parameters is that no ground motion records are available in Bangladesh and selection of attenuation laws is a difficult task. Recognizing this difficulty, Bolt (1987), who carried out a detailed seismicity study for a major bridge project, recommended that "... the Jamuna Bridge Project, install, at an early date, several strong motion accelerometers near the bridge site".

Hattori (1979) has prepared contours for velocity and acceleration for different regions for different return periods. Some of these are shown in Figures 10a-10c. Further work is now in progress to compare these with other available data and it is expected that the Building Code will contain some recommendations. A recent study (Kundu, 1992) has tried to compare the various equations for the significant earthquakes (Figure 11).

3.4 Structural Design Practice

The Committee of Experts prepared an outline of Code of Practice for Earthquake Resistant Design of Buildings (Annex A). The provisions of the code are being followed in the design of many of the tall buildings (up to 25-30 stories) which are being constructed in Dhaka and Chittagong. This is being taught to undergraduate students at BUET, so that graduates will be familiar with the provisions of the Code.

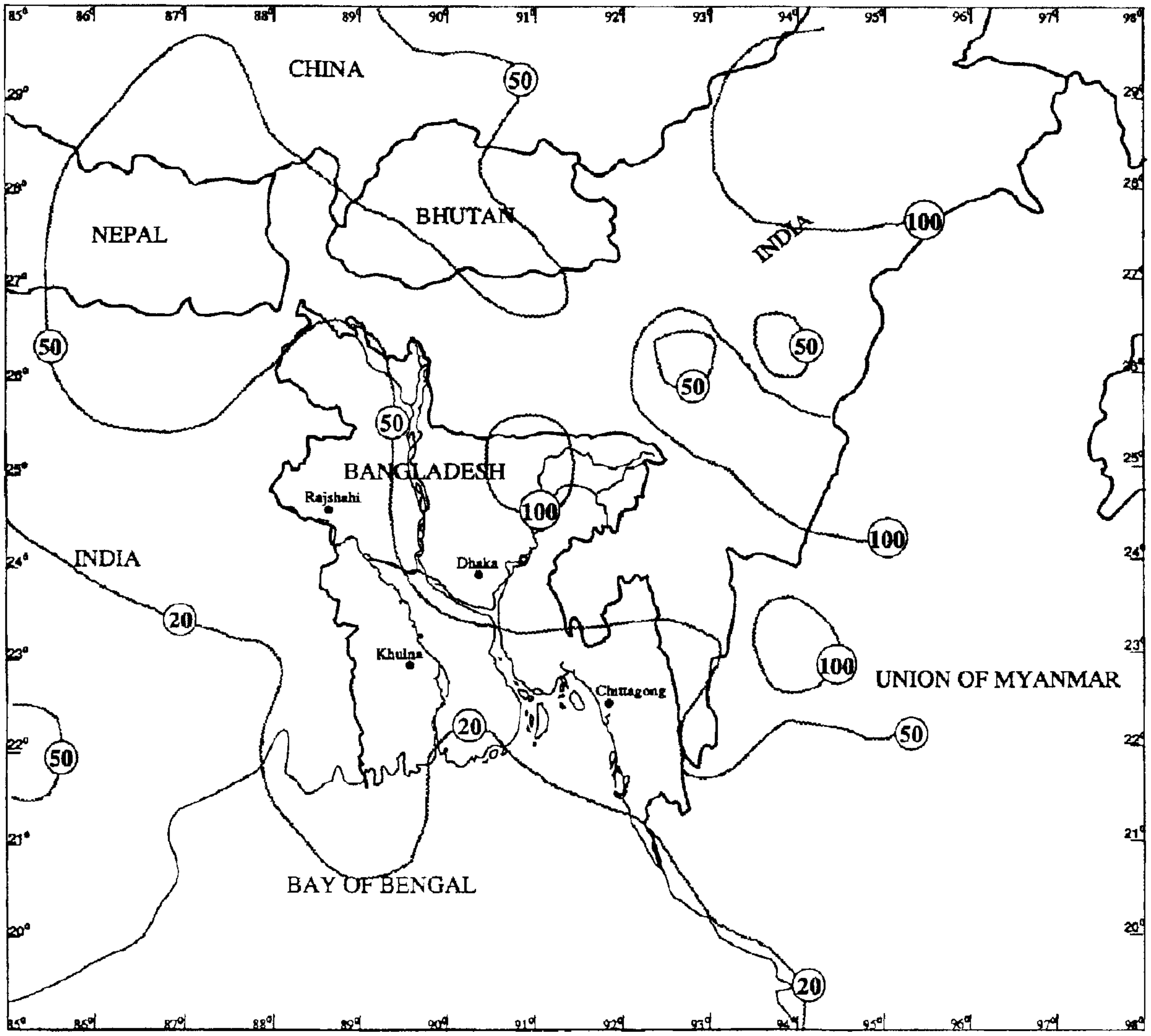
A comparison of the base shear values of the Bangladesh Code with UBC and NBC-INDIA has been made for two buildings (20-story and 10-story). It appears that in both cases the base shear values are being underestimated by the existing provisions (Annexes C and D).

A National Building Code is being prepared and the final draft is expected in June 1993. The guidelines of UBC 1991 are likely to be adopted.

The structural details recommended in ACI 318 are usually followed in high-rise buildings.

3.5 Non-engineered Construction

The vast majority of population live in non-engineered construction (e.g., "Kutcha" or "Semi-pucca" houses). Out of about 17 million houses, about 65% have walls made of straw or bamboo and another 10% have walls of corrugated galvanized iron or wood. The seismic risk of these houses is very small. The occupants of houses with walls made of mud/sunburnt bricks or burnt clay brick (20% and 5%, respectively) are subject to higher seismic risk. In the urban centers, structures with RC floor and roof and brick masonry walls with sand-cement mortar are quite common. With increasing urbanization, there is a trend of vertical extension of these buildings and 5-story buildings with 250 mm thick brick masonry walls are also being built. The recommendations of IAEE for non-engineered brick masonry are known to few engineers, but these are very rarely implemented. These buildings, many of which are being built in area with high seismicity (e.g., in Sylhet), pose a serious threat not only to the occupants but also to those living around the building.



LEGEND:

International Boundary

River

Acceleration Contours

Figure10a: Seismic map showing the 50-year ground surface acceleration contours in Bangladesh and neighbourhood