INDIA

- WHERE THE INDIAN AND EURASIAN PLATES CONTINUE TO COLLIDE

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ABSTRACT

The article deals with the present day status of information regarding earthquakes in India. A brief mention is made of the Himalayan earthquakes and attention is drawn to very high seismicity including four great earthquakes exceeding magnitude 8 from 1897 to 1950. Seismic stations and strong motion arrays in operation are briefly commented upon. A mention is made of the existing earthquake resistant design of structures, building codes and insurance policies. A reference is made to a medium-term forecast, probabilistic seismic hazards estimates and scenarios developed if past major earthquakes were to repeat today. With India being the site of the largest and most sustained reservoir induced earthquakes at Koyna, a mention is also made of the worldwide problem of reservoir induced seismicity.

1 INTRODUCTION

The seismic activity associated with the Himalayan Fontal Arc, approximately 2,000 km in length from the western syntaxis in Kashmir to the eastern syntaxis in Assam, has been very intense. Several damaging earthquakes have occurred in the region. Table 1 depicts earthquakes of magnitude ≥7.5 that occurred in this region since 1897. The northward movement of the Indian plate caused continental collision with an estimated rate varying from 44 to 61 mm per year, and as a result of this collision with the Eurasian plate, the Himalayan mountain belt was created (Minister and Jordan, 1978; Armijo, 1989; and others). The seismic activity of the region as a result of the continued collision between the Indian and Eurasian plates was discussed by Wadia (1935), Crawford (1974), Gansser (1981), Valdiya (1981 and 1992) and others. In this short article, a reference is being made to major works dealing with earthquakes, their occurrences, locations and hazard assessment in India. Recently, a special volume was published which deals with almost all aspects of earthquakes in India (Gupta, 1992a). This reference should be used for detailed information. In the present article, we shall briefly discuss earthquake catalogues, instrumentation, codes, insurance, forecasts and reservoir induced earthquakes.

2 HIMALAYAN BELT SEISMICITY

The Himalayan Frontal Arc has been seismically one of the most active intra-continental regions in the world. Figure 1, updated from Chandra (1978, 1992), depicts all earthquakes of magnitude 7 or larger that occurred in the vicinity of the Himalayan Frontal Arc as well as those earthquakes that claimed human lives. A special mention must be made of the four great earthquakes, namely, the 1897 Shillong earthquake, the 1905 Kangra earthquake, the 1934 Bihar-Nepal earthquake and the 1950 Assam-China border earthquake, all exceeding magnitude 8. These four great earthquakes occurred in a short time span of 53 years. There is a special chapter "Some Great Indian Earthquakes" in the famous textbook "Elementary Seismology" by Prof. C. F. Richter (1958). The 1897 great earthquake and studies carried out by Oldham (1899) have become a landmark in the seismology literature. The 1934 Bihar-Nepal earthquake caused a 200 km long and up to 60-70 km wide slump belt (Figure 2) due to soil liquefaction where nothing survived. The earthquakes continue to occur. The latest killer Uttarkashi earthquake occurred on October 20, 1991. Although the earthquake was only of body wave magnitude 6.6, it claimed over 1,500 human lives and caused widespread destruction. As a matter of fact, for the calendar year 1991, the Uttarkashi earthquake has been described as the most significant earthquake of the year (Episodes, 1992). Field investigations carried out by engineers and seismologists reveal that poor construction of the buildings in the region is mainly responsible for the large number of human lives lost. Well-constructed houses, even in high intensity area, withstood the earthquake.

TABLE 1: EARTHQUAKES OF M ≥7.5 IN THE HIMALAYAN REGION SINCE 1897

Date	Lat.(°N)	Long.(°E)	Location	Magnitude
June 12, 1897	25.9	91.8	Assam	8.7
Apr. 4, 1905	33.0	76.0	Kangra Valley	8.6
Dec. 12, 1908	26.5	97.0	N. Burma	7.5
May 23, 1912	21.0	97.0	-	8.0
July 8, 1918	24.5	91.0	Assam	7.6
Jan. 27, 1931	25.6	96.0	-	7.6
Jan. 12, 1934	26.5	86.5	Bihar-Nepal	8.4
May 30, 1935	29.5	66.7	Quetta	7.6
Sep. 12, 1946	23.5	96.0	-	7.7
July 29, 1947	28.5	94.0	N.E.Assam	7.9
Aug. 15, 1950	28.5	96.7	Assam	8.7
Nov. 18, 1951	31.1	91.4	-	8.0
Aug. 17, 1952	30.5	91.5	-	7.5

3 EARTHQUAKE CATALOGUES

The earliest catalogue of earthquakes in India was prepared by Oldham (1883) which is an excellent source of historical earthquakes in the region. In recent years, earthquake catalogues have been prepared by Bapat et al. (1983), Tandon and Srivastava (1974), Chandra (1978, 1992), Gupta et al. (1986) and others. It may be mentioned that the earliest entry in these catalogues goes back to the 16th century. In an interesting study, Gupta et al. (1986) have examined the North-East India region and assessed the various available catalogues, looking into the historical records and finally came up with an acceptable catalogue for the region which is divided into three categories:

1. Historical earthquakes from 1548 to 1897
2. Pre-Worldwide Standard Seismograph Network data (1897 to 1962)
3. Post-1963 data

For (1) and (2), Gupta et al. (1986) found several inconsistencies which were set right. It is desirable that similar exercises are carried out for other parts of the country as well.

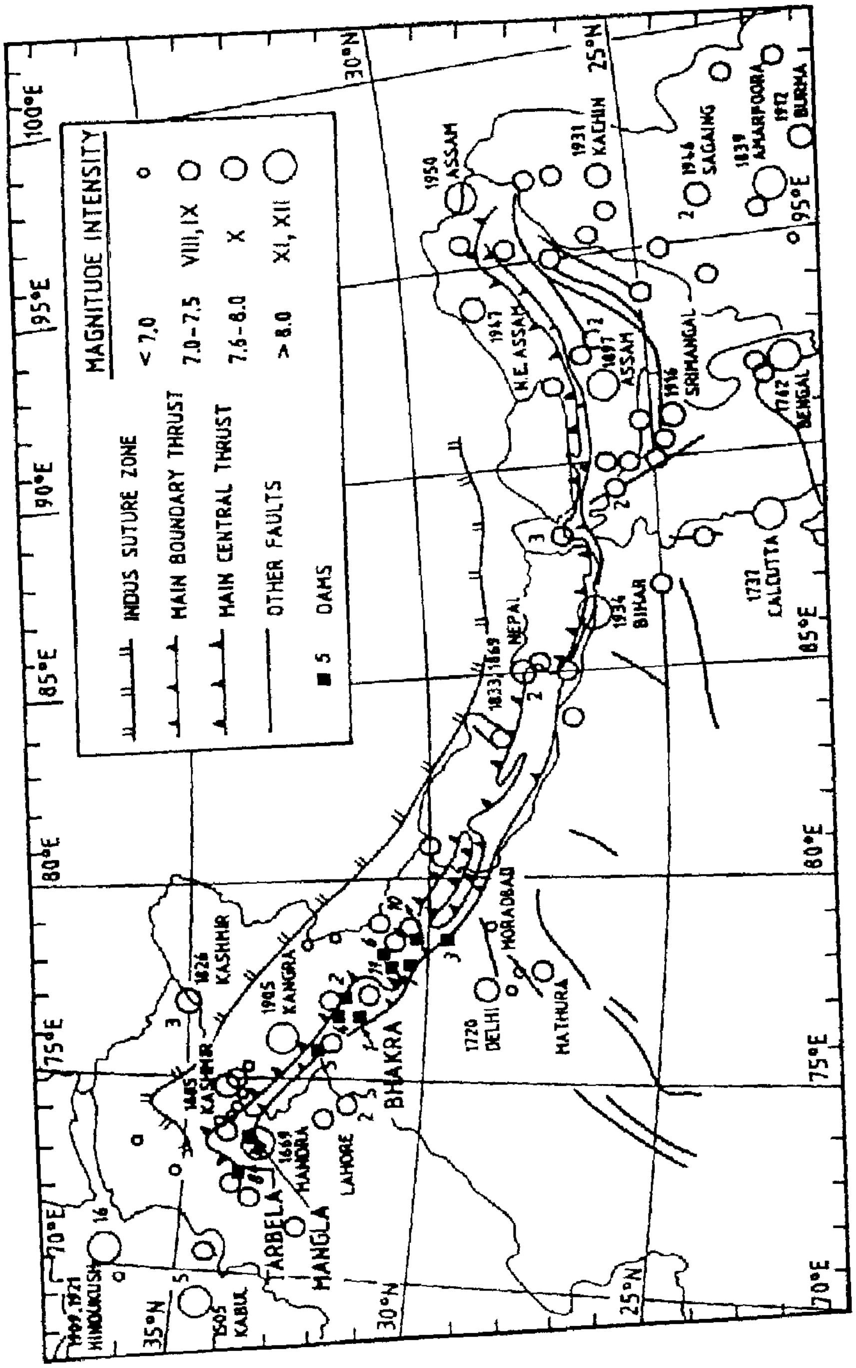

Figure 1 · Earthquakes of magnitude 7 and larger as well as earthquakes which claimed human lives in the Himalayan Frontal Arc region (updated from Chandra, 1978)

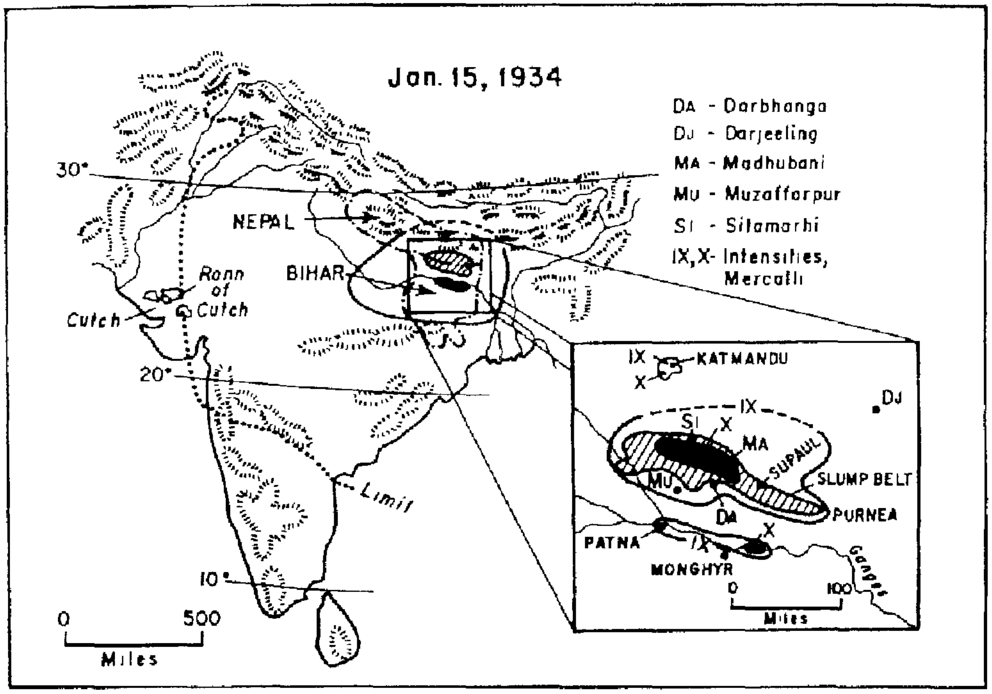

Figure 2: Slump belt created by the great 1934 Bihar-Nepal earthquake (after Richter, 1958)

4 INSTRUMENTATION

Consequent to the occurrence of the great Shillong earthquake on June 12, 1897, with a magnitude of 8.7, the need for installation of seismic stations was strongly felt. The first seismometer in India was installed at Alipur in Calcutta on December 1, 1898. The second and third stations at Colaba in Bombay and Madras were installed in 1899. The India Meteorological Department is the central agency responsible for maintaining the national network of seismic stations. Figure 3, adopted from Srivastava (1992), gives the distribution of the permanent seismological stations operating in the country. The National Geophysical Research Institute, Hyderabad, in collaboration with the Regional Research Laboratory, Jorhat, is operating a major network consisting of two telemetering seismic arrays and some 20 stand-alone stations in the North-East India region. The Wadia Institute of Himalayan Geology, Dehra Dun, is operating about a dozen stations in Western Himalaya. In addition to this, there are several other dozen stations operated regionally for specific requirements such as monitoring sites of water reservoirs, rockbursts, nuclear power plants, etc.

5 STRONG MOTION ARRAYS

The first strong motion record in India was created by the Koyna earthquake of December 10, 1967. In recent years, the importance of recording strong motion data close to the epicenter has been well recognized. On the basis of the recommendation of the 6th World Conference on Earthquake Engineering in Delhi in 1977 and the International Workshop on Strong Motion Measurements held in Hawaii, USA, in 1978, the Department of Science and Technology, Government of India, has started installation of strong motion seismic arrays in Kangra region of Himachal Pradesh, Garhwal region of Uttar Pradesh and the Shillong region of North-East India. Each of these three arrays has 50 instruments. These are depicted in Figure 4. Recently, Chandrasekharan and Das (1992) have given a gist of results obtained by these arrays. The North-East India region has been relatively more active and four earthquakes triggered accelerographs in the Shillong array in 1986 and 1988 resulting in 77 three component accelerograms. The recent Uttarkashi earthquake of October 20, 1991 created four strong motion records. These accelerograms are proving to be extremely useful in making a realistic estimate of strong ground motion in the earthquake prone areas.

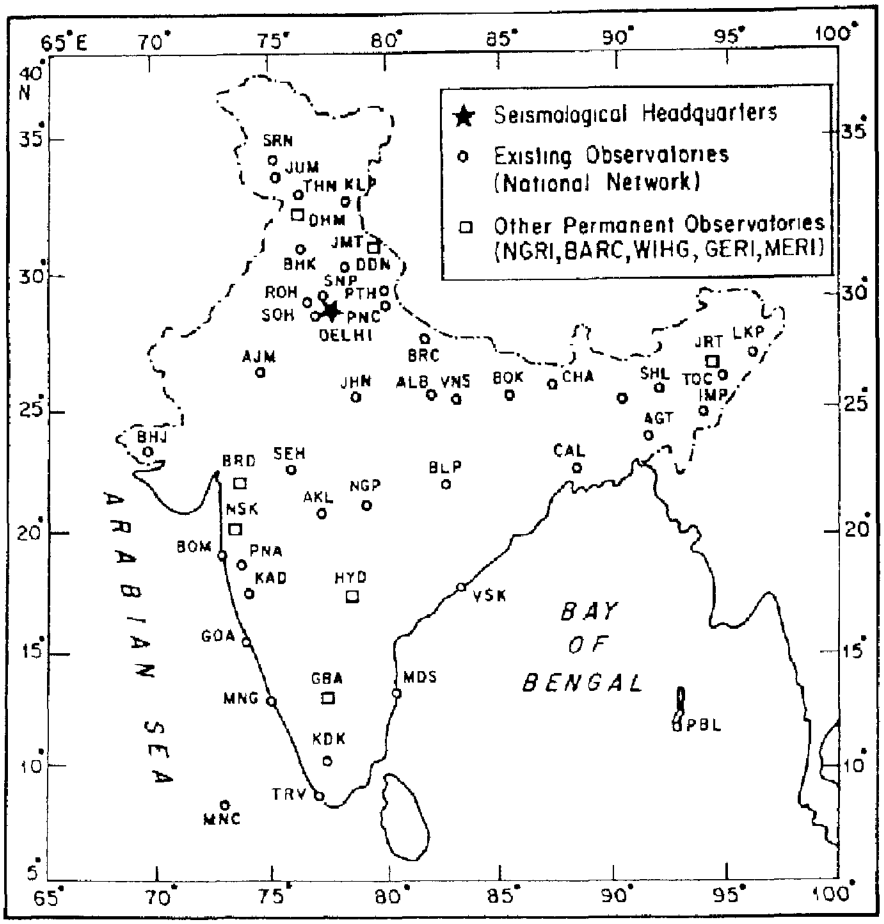

Figure 3: Permanent seismic stations operating in India (after Srivastava, 1992)

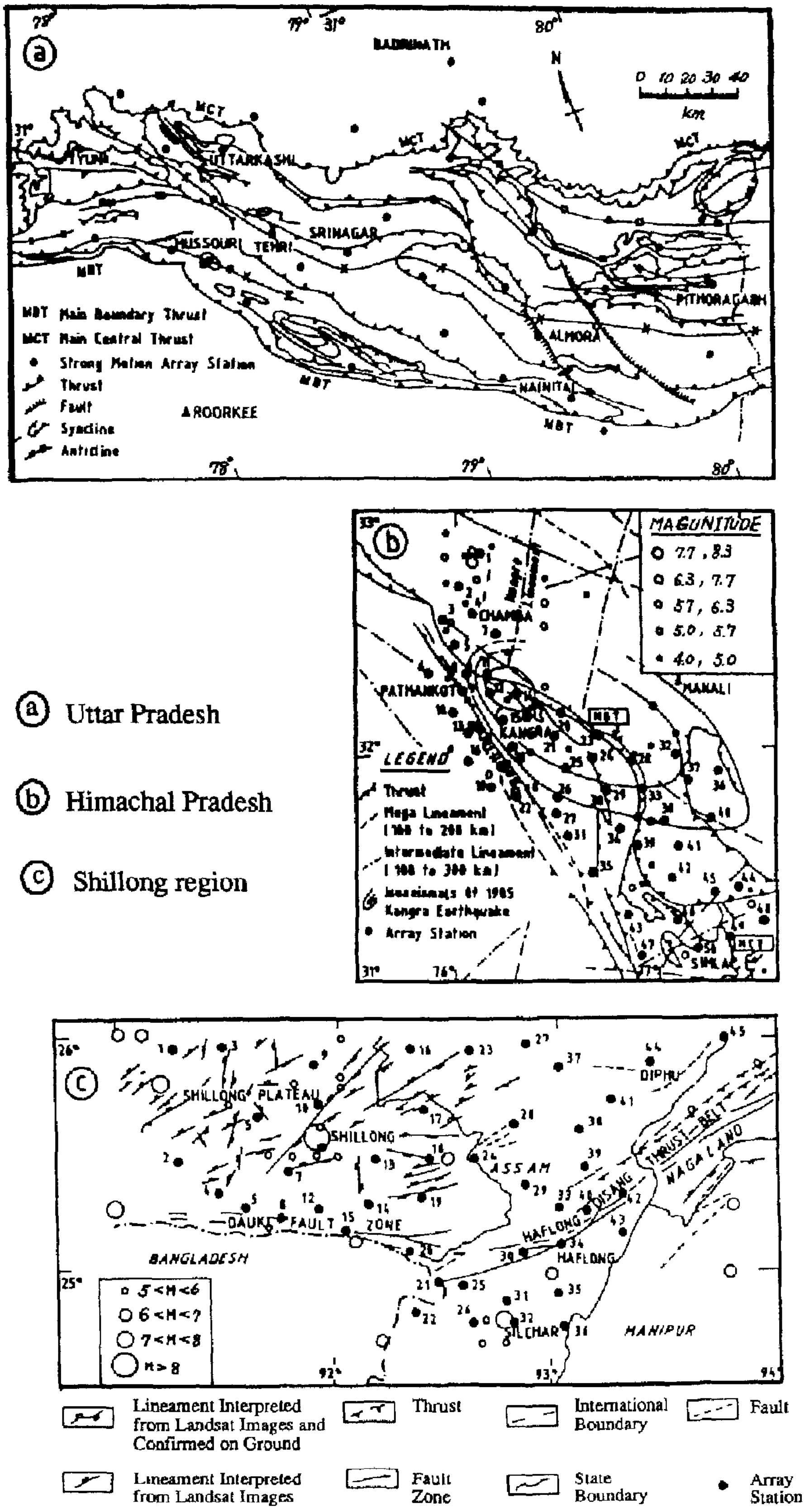

Figure 4: Strong motion arrays in the Indian region (after Chandrasekharan et al., 1992)

6 BUILDING CODES

The Indian Standard Institution has the responsibility of developing criteria for earthquake resistant design of structures. It formulated the first code in 1962 which was subsequently revised in 1966, 1970, 1975 and the latest, in 1984. These revisions were called for as more seismic data have been collected and additional knowledge and experience have been gained since the publication of the first code. Figure 5, adopted from Indian Standard Institution (1984), depicts five seismic zones into which the entire country has been divided. In the description of this zoning map, Indian Standard Institute has noted that the seismic coefficient required in the design of any structure depends on several variable factors and it is very difficult to determine exactly the seismic coefficient in each given case. It was therefore felt necessary to broadly indicate the seismic coefficient that could generally be adopted in different parts or zones of the country. However, it is necessary that rigorous analysis is made considering all the factors involved for important projects in order to arrive at a suitable seismic coefficient for design. The object of the seismic zoning map is to classify the areas of the country into a number of zones depicting reasonably the maximum intensities in future earthquakes. The intensities associated with zone number I, II, III, IV, and V are V or less, VI, VII, VIII, and IX and above on the Modified Mercalli intensity scale, respectively. The design value chosen for a structure is obtained by multiplying the basic horizontal seismic coefficient for the zone with an appropriate importance factor. The following assumptions are used by the Indian Standard Institute (1984):

1. Earthquake causes impulsive ground motion which is complex and irregular in character, changing period and amplitude each lasting for a short duration. Therefore, resonance of the type as visualized under steady state sinusoidal excitations will not occur as it would need time to build up such amplitudes.

2. Earthquake is not likely to occur simultaneously with wind or maximum flood or maximum sea waves.

3. The value of elastic modulus of materials, wherever required, may be taken as for static analysis unless a more definite value is available for use in such condition.

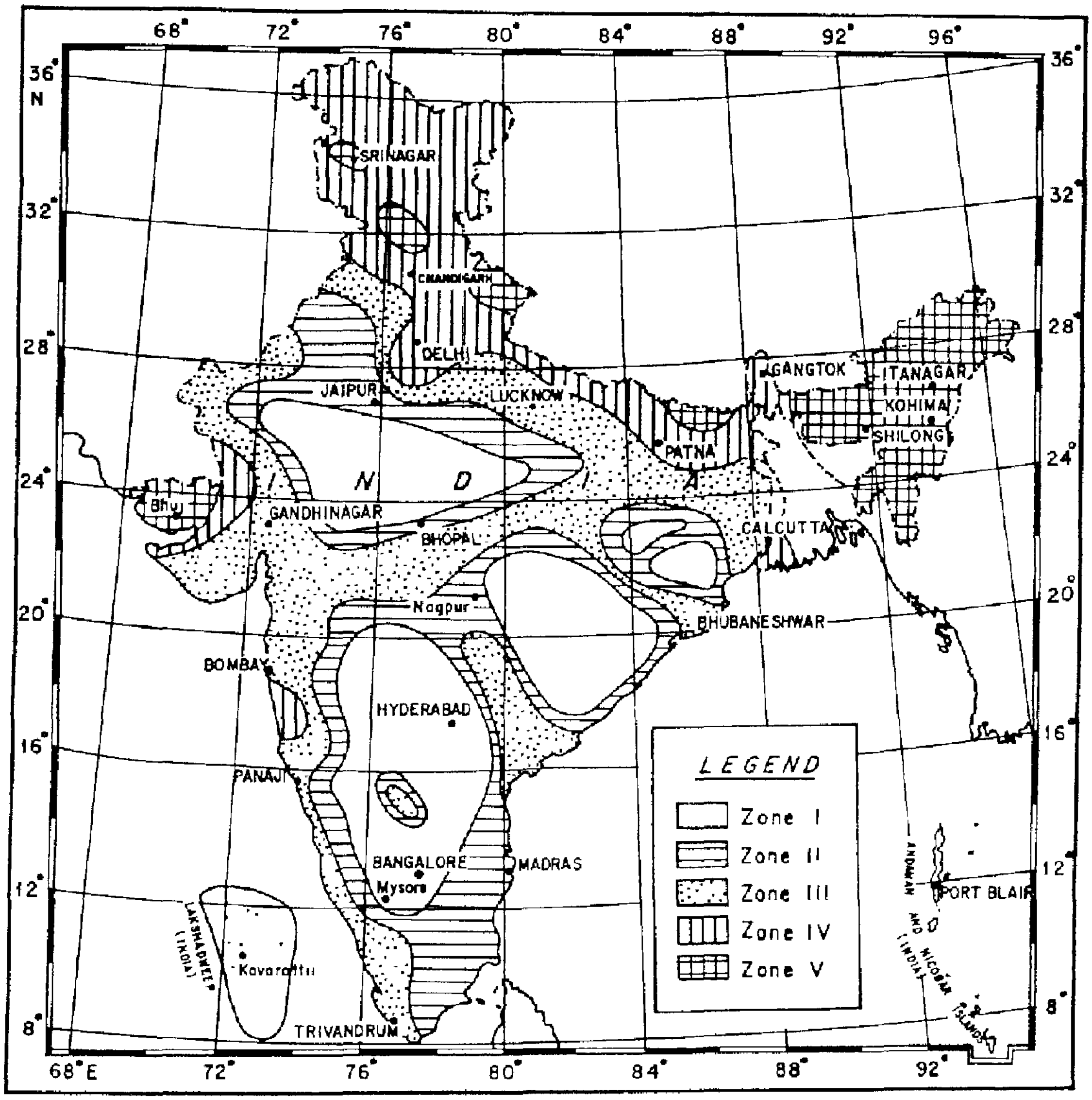

Figure 5: Seismic zoning map of India (after Indian Standard Institute, 1984)

7 INSURANCE

Insurance for structures against damage caused by earthquakes is available only as an extension of other policies like fire policy, but not exclusively, except in cases of structures erected underground such as reservoirs, wells, roads, water pipes, etc. Basically, the buildings are classified under the following categories:

Buildings constructed with

i) reinforced concrete
or ii) reinforced concrete frame with brick panel walls
or iii) walls of brick and/or stone having structural steel frame.

- Wholly or partly open sided buildings constructed as above
- Outdoor plants (with or without roof)
- Structures having panels of masonry or concrete or claddings of asbestos sheeting or corrugated iron sheeting or similar non-combustible material with metal or RCC frame.

Buildings constructed with

i) burnt bricks entirely, with an outside bracing of timber filled with bricks
or ii) walls of budgie, brick nogging wood and/or metal and/or open sheds
or iii) steel framework with corrugated asbestos, cement sheeting walls.

Buildings constructed with

i) walls of unburnt bricks and/or mud
or ii) other than as provided for above.

- Underground steel tanks used for storage of petrol, diesel oil.

The country has been divided into four zones as depicted in Figure 6 and the rate of insurance is calculated based on the type of construction and its location on the specific zone as given in Table 2.

TABLE 2: DETAILS OF INSURANCE PAYMENT FOR HOUSES

Class of Construction	Rate per annum (in thousand rupees)			
	Risk code No. 981	Risk code No. 982	Risk code No. 983	Risk code No. 984
	Zone I	Zone II	Zone III	Zone IV
A	2.90	1.45	0.60	0.15
B	3.70	1.85	0.70	0.20
C	4.40	2.20	0.90	0.20
D	5.20	2.60	1.05	0.25

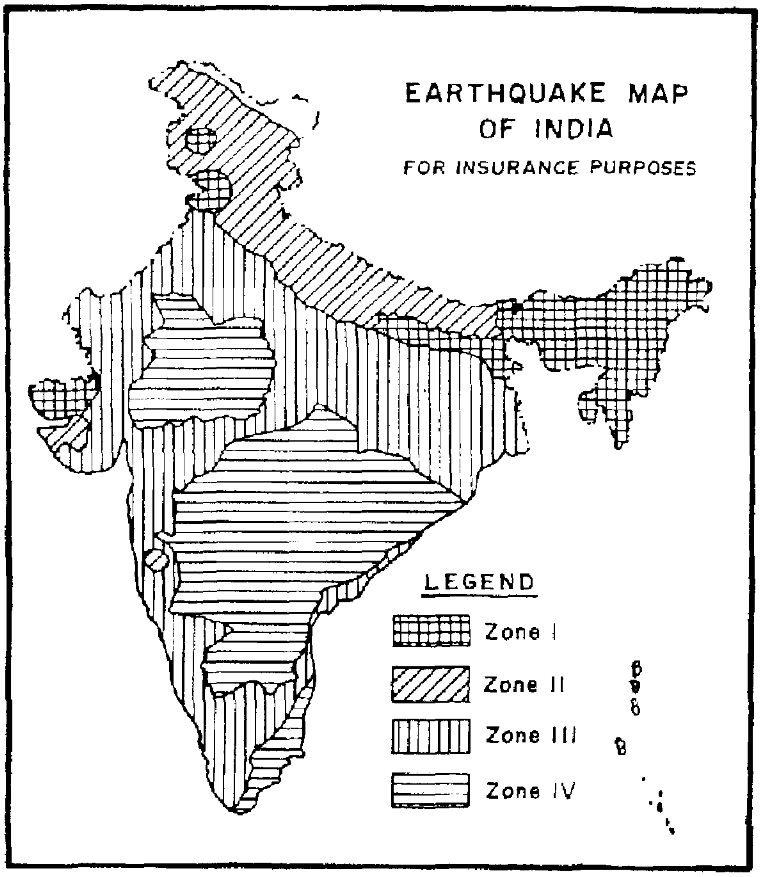

Figure 6: Earthquake map of India for insurance purposes

8 FORECASTS

8.1 A medium-term earthquake forecast in the NE India region

There is a global effort to establish precursor patterns that precede major earthquakes. An effort in this direction was made by Gupta and Singh (1986) in the North-East India region. Encouraged by the discovery of the precursory swarm and quiescence preceding the Cachar earthquake of December 30, 1984, Gupta and Singh (1986) carried out an in-depth study of all earthquakes of magnitude greater than or equal to 7.5 since 1897 and several smaller magnitude earthquakes that occurred after 1962. In their study they discovered that the main shock magnitude (M_m) has correspondence with the magnitude of largest events (M_p) in the swarm and the time interval (T_p) between the onset of the swarm and the occurrence of the main shock in days. Following are the relations they found:

$M_m = 1.37\, M_p - 1.41$ and

$M_m = 3 \log T_p - 3.27$

Gupta and Singh (1986) observed that it is important to recognize swarm and quiescence before the occurrence of the main shock. They discovered one such region in the vicinity of the Indo-Burma border and concluded that

1. Moderate magnitude to great earthquakes in the North-East India region are found to be preceded, generally, by well-defined earthquake swarms and quiescence periods.
2. On the basis of an earthquake swarm and quiescence period, an area bound by 21°N and 25.5°N latitude and 93°E and 96°E longitude is identified to be the site of a possible future earthquake of M 8±0.5 with a focal depth of 100±40 km. This earthquake should occur anytime from now. Should it not occur till the end of 1990, this forecast could be considered as a false alarm.

The epochs of background/normal seismicity, swarm and quiescence for the above mentioned region are included in Figure 7. It was pointed out by Gupta and Singh (1989) that the annual frequency during the swarm period is several fold higher than the background seismicity and quiescence epochs. Findings of Gupta and Singh were discussed in the symposium "Earthquake Hazard Assessment and Prediction" held during the XIX IUGG General Assembly at Vancouver, Canada in 1987 (Gupta and Singh, 1989). The occurrence of the August 6, 1988 earthquake with focal parameters mentioned in Table 3 has made this medium-term forecast come true. This success encourages one to make similar investigations elsewhere in the Himalayan Frontal Arc for concentrating hazard related investigations in a few critical areas.

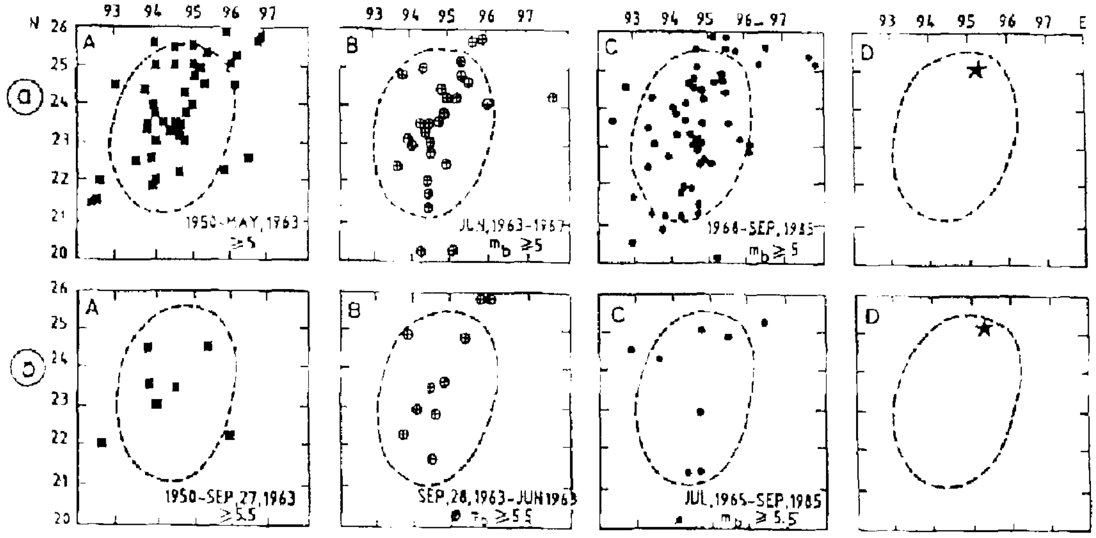

Figure 7: Earthquake in the vicinity of India-Burma border region. Earthquake data from 1950 through September 1985 are presented for (a) earthquake of $M_b \geq 5.0$ and (b) earthquake of $M_b \geq 5.5$. The epochs of background/normal seismicity (A, solid square), swarm (B, circle with cross), and quiescence (C, solid circle) are well identified. The August 6, 1988 earthquake (star) occurred in the elliptical zone of preparation for a future earthquake delimited by Gupta and Singh (1986).

TABLE 3: FOCAL PARAMETERS OF THE AUGUST 6, 1988 EARTHQUAKE

Earthquake Parameters	Forecast (Gupta and Singh, 1986)	Occurrence NEIS (Preliminary determination)
Epicenter	21^{0}N to 25.5^{0}N 93^{0}E to 96^{0}E	25.149^{0}N 95.127^{0}E
Magnitude	8±0.5	7.3
Depth	100±40 km	90.5 km
Time	February 1986 to December 1986	August 6, 1988 (00.36.26.9 G.C.T)

8.2 Probabilistic seismic hazard map of Himalaya

Recently, Khattri (1992) has discussed scientific issues in preparing well-estimated seismic hazard maps for the Indian region. He has also prepared a probabilistic seismic hazard map for Himalaya and adjoining areas for exposure period 1981-2031. This map depicts contours of peak acceleration in %g with 10% probability of exceedance in the exposure period (Figure 8).

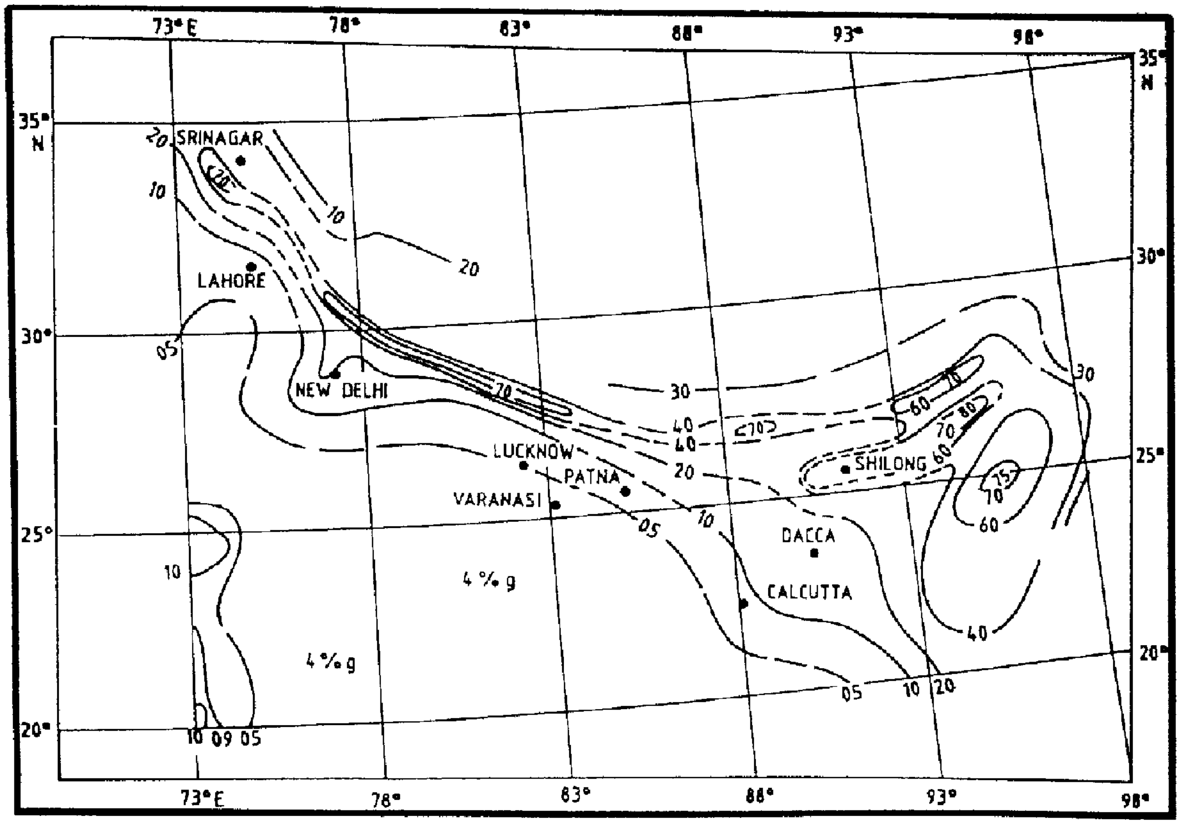

Figure 8: Probabilistic seismic hazard map of Himalaya and adjoining areas for the exposure period from 1981 to 2031 after Khattri (1992). The diagram depicts the contours of peak acceleration in % g with 10% probability of exceedance in the exposure period.

8.3 Potential of damage during future earthquakes

It may be noted that the population density has increased several fold in the Himalayan foothills. However, construction continues to be of poor quality. As a consequence the number of people likely to be affected by great earthquakes has increased considerably. In an interesting study, Arya (1992) has estimated the damage scenario in the Kangra region where a great earthquake occurred in 1905. His basis of damage assessment is that if such an earthquake was to repeat today the distribution of the intensity would be the same as in 1905 (Figure 9) putting areas of 500, 2400, 5000, and 26000 km sq. under intensities X, IX, VIII and VII, respectively, on the MM scale. Based on the building material and construction practices prevalent in the region, Arya has estimated that 1, 45, 400 houses will collapse completely and some 2, 67, 800 houses will suffer severe damage. Depending upon the time of day when the earthquake will occur, the loss of human lives would vary between 88,000 and 344,000 (Table 4). It is essential to retrofit some important buildings to reduce hazard.

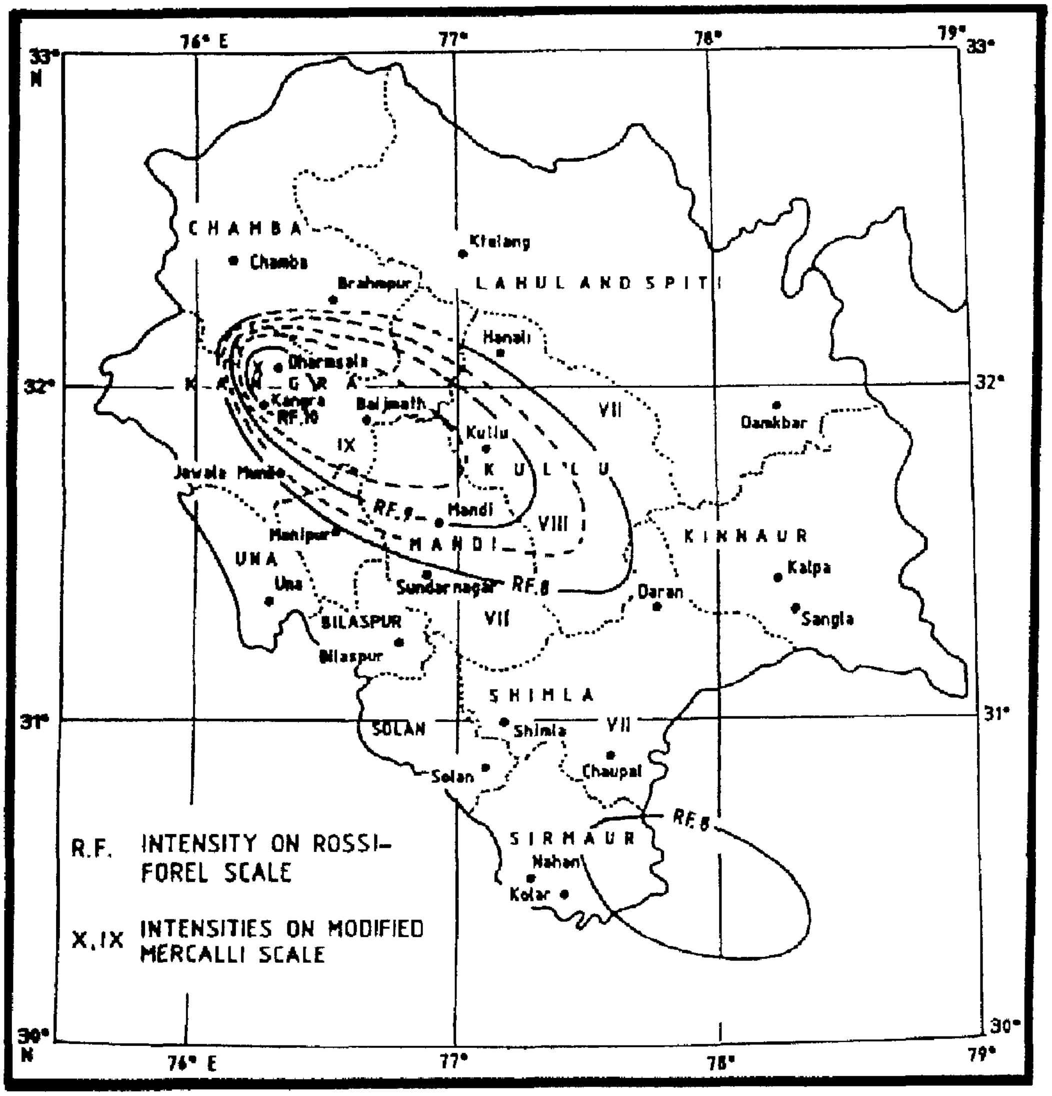

Figure 9: Intensities of the great Kangra earthquake of 1905 (after Arya, 1992)

TABLE 4: ESTIMATED DEATH POTENTIAL IF THE KANGRA EARTHQUAKE OF 1905 WAS TO REPEAT (AFTER ARYA, 1992)

Time of occurrence	Deaths in collapsed houses	Deaths in partly collapsed houses	Total potential deaths
Midnight (sleeping)	40%	20%	344, 000
Morning (awake and sleeping)	20%	10%	177,000
Noon time (out working)	10%	5%	88,000

9 RESERVOIR INDUCED EARTHQUAKES

Huge artificial water reservoirs are created all over the world for generating hydroelectricity, flood control and irrigation purposes. Carder (1945) pointed out for the first time the association of earthquakes with reservoir loading at Lake Mead in the United States. Earthquakes of magnitude 6 or greater have occurred at Hsinfengkiang, China, 1962; Kariba, Zambia-Zimbabwe border, 1963; Kremasta, Greece, 1966; and Koyna, India, 1967. Recent important examples of induced earthquakes are those of Lake Aswan in Egypt and Bhatsa in India. In a recent study, Gupta (1992b) has compiled all the information regarding reservoir induced earthquakes. Reservoir induced earthquakes can locally be very damaging and it is necessary that proper care is taken in selecting sites which have less potential of induced earthquakes. Techniques for selecting less vulnerable sites are being developed.

10 CONCLUDING REMARKS

This article has very briefly touched issues of importance and drawn important references as far as earthquake studies and hazard assessment in India are concerned.

During the WSSI meeting at Bangkok in February 1993 discussions with colleagues from adjoining countries underlined the importance and the need to exchange earthquake related data and experience. It would be important to exchange earthquake catalogues, and information on building codes, develop scenarios for future earthquake occurrences and look into specific site problems such as liquefaction. Needless to say, it is very important to improve the strong motion data acquisition capabilities in various countries, strengthen post-disaster surveys and train concerned manpower on how to assess and reduce seismic hazard.

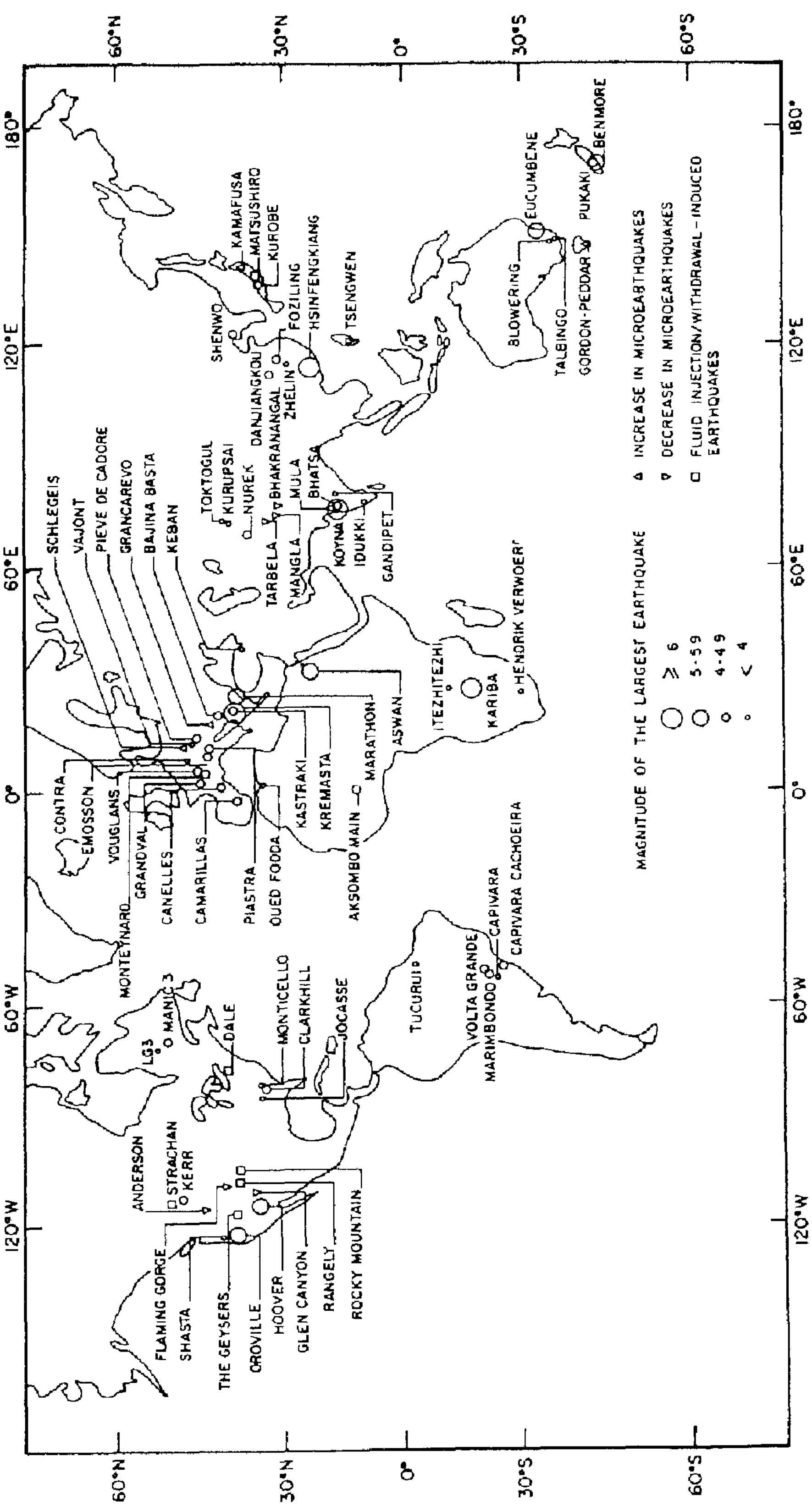

Figure 10: Worldwide distribution of reservoir induced earthquakes (after Gupta, 1992)

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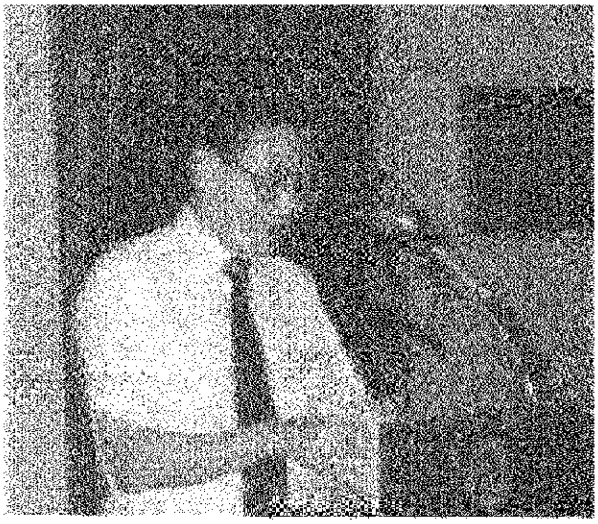

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