MMI	V	VI	VII	VIII	IX	X
PGA(g)	0.03-0.04	0.06-0.07	0.10-0.15	0.25-0.30	0.50-0.55	>0.60

Table 3. PGAs during shaking of different intensities. *Source: B A Bolt, Earthquakes, WH Freeman and Co., New York, 1993.*

ground shaking. These are critical for cost-effective earthquake-resistant design.

Based on data from past earthquakes, scientists Gutenberg and Richter in 1956 provided an approximate correlation between the Local Magnitude M_L of an earthquake with the intensity I_0 sustained in the epicentral area as: $ML \approx 2/3\ I_0 + 1$. (For using this equation, the Roman numbers of intensity are replaced with the corresponding Arabic numerals, e.g., intensity IX with 9.0). There are several different relations proposed by other scientists.

Suggested Reading

[1] C F Richter, *Elementary Seismology*, WH Freeman and Company Inc, San Francisco, USA. 1958. (Indian Reprint in 1969 by Eurasia Publishing House Private Limited, New Delhi).

[2] http://neic.usgs.gov/neis/general/handouts/magnitude_intensity.html

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Learning Earthquake Design and Construction
4. Where are the Seismic Zones in India?

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Basic Geography and Tectonic Features

India lies at the northwestern end of the *Indo-Australian Plate*, which encompasses India, Australia, a major portion of the Indian Ocean and other smaller countries. This plate is colliding against the huge *Eurasian Plate* (*Figure* 1) and going under the Eurasian Plate; this process of one tectonic plate getting under another is called *subduction*. A sea, *Tethys*, separated these plates before they collided. Part of the lithosphere, the Earth's Crust, is covered by oceans and the rest by the continents. The former can undergo subduction at great depths when it converges against another plate, but the latter is buoyant and so tends to remain close to the surface. When continents converge, large amounts of shortening and thickening takes place, like at the Himalayas and the Tibet.

Keywords
Seismic zones, past earthquakes.

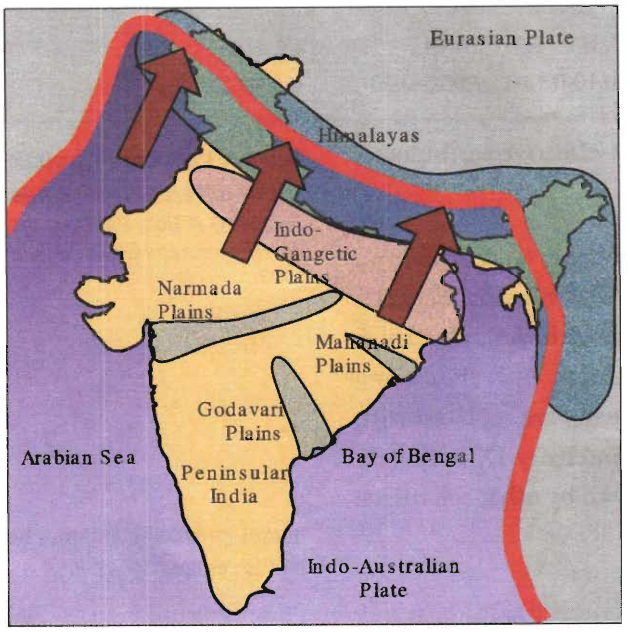
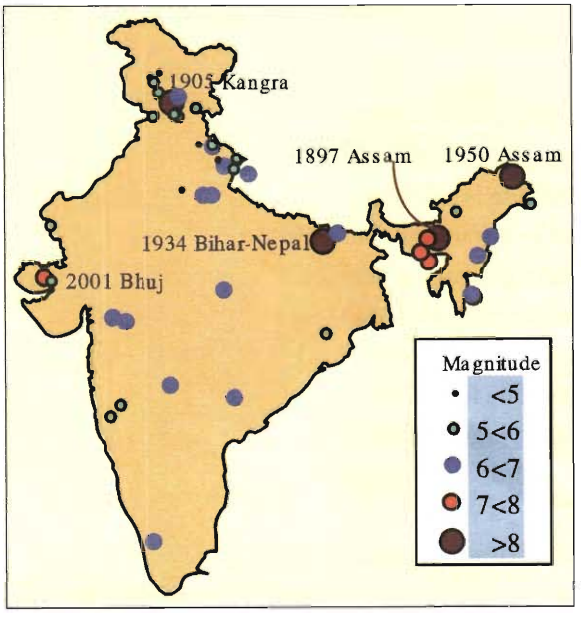


Figure 1. Geographical Layout and Tectonic Plate Boundaries at India.

Three chief tectonic sub-regions of India are the mighty *Himalayas* along the north, the plains of the Ganges and other rivers, and the peninsula. The Himalayas consist primarily of sediments accumulated over long geological time in the Tethys. The Indo-Gangetic basin with deep alluvium is a great depression caused by the load of the Himalayas on the continent. The peninsular part of the country consists of ancient rocks deformed in the past Himalayan-like collisions. Erosion has exposed the roots of the old mountains and removed most of the topography. The rocks are very hard, but are softened by weathering near the surface. Before the Himalayan collision, several tens of millions of years ago, lava flowed across the central part of peninsular India leaving layers of basalt rock. Coastal areas like Kachchh show marine deposits testifying to submergence under the sea millions of years ago.

Figure 2. Some Past Earthquakes.



Prominent Past Earthquakes in India

A number of significant earthquakes occurred in and around India over the past century (*Figure* 2). Some of these occurred in populated and urbanized areas and hence caused great damage. Many went unnoticed, as they occurred deep under the Earth's surface or in relatively un-inhabited places. Some of the damaging and recent earthquakes are listed in *Table* 1. Most earthquakes occur along the Himalayan plate boundary (these are *inter-plate* earthquakes), but a number of earthquakes have also occurred in the peninsular region (these are *intra-plate* earthquakes).

Date	Event	Time	Magnitude	Max Intensity	Deaths
16 June 1819	Cutch	11:00	8.3	IX	1,500
12 June 1897	Assam	16:25	8.7	XII	1,500
8 Feb. 1900	Coimbatore	03:11	6.0	VII	Nil
4 Apr. 1905	Kangra	06:10	8.0	X	19,000
15 Jan. 1934	Bihar-Nepal	14:13	8.3	X	11,000
15 Aug. 1950	Assam	19:39	8.6	X	1,530
21 Jul. 1956	Anjar	21:02	6.1	IX	115
10 Dec. 1967	Koyna	04:30	6.5	VIII	200
23 Mar. 1970	Bharuch	20:56	5.2	VII	30
21 Aug. 1988	Bihar-Nepal	04:39	6.6	IX	1,004
20 Oct. 1991	Uttarkashi	02:53	6.4	IX	768
30 Sep. 1993	Killari (Latur)	03:53	6.2	VIII	7,928
22 May 1997	Jabalpur	04:22	6.0	VIII	38
29 Mar. 1999	Chamoli	00:35	6.6	VIII	63
26 Jan. 2001	Bhuj	08:46	7.7	X	13,805

Table 1. Some Past Earthquakes in India.

Four Great earthquakes (M>8) occurred in a span of 53 years from 1897 to 1950; the January 2001 Bhuj earthquake (M7.7) is almost as large. Each of these caused disasters, but also allowed us to learn about earthquakes and to advance earthquake engineering. For instance, 1819 Cutch Earthquake produced an unprecedented ~3m high uplift of the ground over 100km (called *Allah Bund*). The 1897 Assam Earthquake caused severe damage up to 500km radial distances; the type of damage sustained led to improvements in the intensity scale from I-X to I-XII. Extensive liquefaction of the ground took place over a length of 300km (called the *Slump Belt*) during 1934 Bihar-Nepal earthquake in which many buildings and structures went afloat.

The timing of the earthquake during the day and during the year critically determines the number of casualties. Casualties are expected to be high for earthquakes that strike during cold winter nights, when most of the population is indoors.

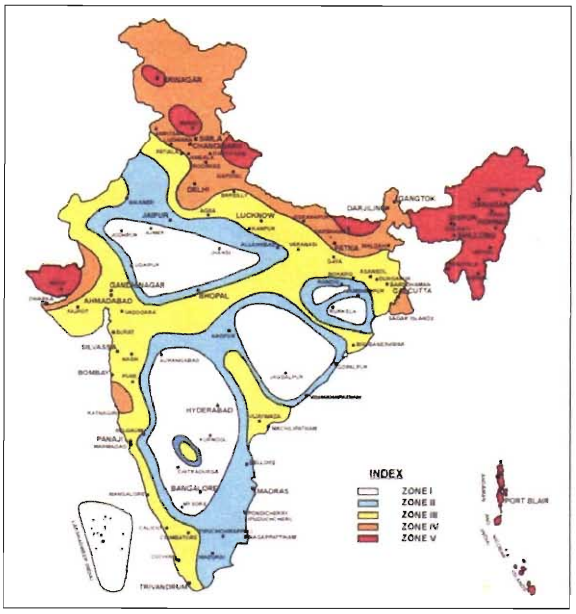


Figure 3. Current Indian Seismic Zone Map. (IS: 1893 -1984).

Seismic Zones of India

The varying geology at different locations in the country implies that the likelihood of damaging earthquakes taking place at different locations is different. Thus, a seismic zone map is required so that buildings and other structures located in different regions can be designed to withstand different level of ground shaking. The current zone map subdivides India into five zones – I, II, III, IV and V (*Figure* 3). The maximum Modified Mercalli (MM) intensity of seismic shaking expected in these zones are V or less, VI, VII, VIII, and IX and higher, respectively. Parts of Himalayan boundary in the north and northeast, and the Kachchh area in the west are classified as zone V.

The seismic zone maps are revised from time to time as more understanding is gained on the geology, the seismotectonics and the seismic activity in the country. For instance, the Koyna earthquake of 1967 occurred in an area classified in zone I as per map of 1966. The 1970 version (same as *Figure* 3) of code upgraded the area around Koyna to zone IV. The Killari (Latur) earthquake of 1993 occurred in zone I. The new zone map under print (*Figure* 4) places this area in zone III. The new zone map

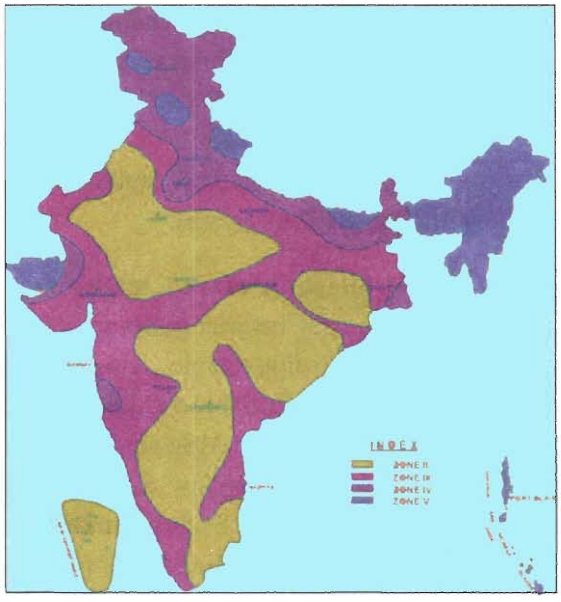


Figure 4. Revised Indian Seismic Zone Map. (under print by BIS).

will now have only four seismic zones II, III, IV and V. The areas falling in seismic zone I in the current map are merged with those of seismic zone II. Also, the seismic zone map in the peninsular region is being modified. Madras will come under seismic zone III as against zone II currently.

The national Seismic Zone Map presents a large-scale view of the seismic zones in the country. Local variations in soil type and geology cannot be represented at that scale. Therefore, for important projects, such as a major dam or a nuclear power plant, the seismic hazard is evaluated specifically for that site. Also, for the purposes of urban planning, metropolitan areas are microzoned. Seismic microzonation accounts for local variations in geology, local soil profile, etc.

Suggested Reading

[1] BMTPC, *Vulnerability Atlas of India*, Building Materials and Technology Promotion Council, Ministry of Urban Development, Government of India, New Delhi, 1997.

[2] S Dasgupta *et al.*, *Seismotectonic Atlas of Indian and its Environs*, Geological Survey of India, Calcutta, 2000.

[3] IS:1893, *Indian Standard Criteria for Earthquake Resistant Design of Structures*, Bureau of Indian Standards, New Delhi, 1984.

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