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Earthquakes in the Himalayan Region: What We Know and What Needs to be Done

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Abstract
Earthquake is the worst natural phenomena. In recent past the earthquake all over the world had taken lots of damages not only human life but also property damage. In 1976 earthquake in China takes away huge amount of life exceeding lakhs. The 1995 Japan earthquake causes huge amount of financial loss. In India Bhuj earthquake in 2001 not only take away human life but also causes huge financial loss. The Kangra earthquake of 1905 has the magnitude of 8.5. So all the earthquake have active effect on the human life as well as nations financial loss to that effect. The Himalayan region earthquakes have very crucial one because of the natural conditions.

Keywords: Earthquakes; Himalaya; Magnitude; Great earthquakes

Introduction
Earthquakes are one of the worst natural calamities. In the recorded history tens of millions of people have lost their lives in earthquakes and property damage has been estimated to be thousands of billions of rupees. In the recent past, the Tangshan earthquake of 1976 in China claimed 242,000 human lives. These are the estimates of the Government of China, while the news media had estimated a loss of half-a-million human lives. The 1995 Kobe earthquake in Japan is now estimated to be the most costly natural disaster, financial losses being estimated to be between 150 to 200 billion US dollars. In India, we have had our own share of earthquake disasters. The 26th January 2001 Bhuj earthquake claimed more than 20,000 human lives and the financial loss is estimated to be about Rs. 50,000 crores. The Himalayan Frontal Arc is seismically one of the most active intra-continental regions in the world. The period between 1897 and 1952 witnessed five earthquakes exceeding magnitude 8. These are: the June 12, 1897 Shillong-Plateau earthquake; the April 4, 1905 Kangra Valley earthquake; the January 15, 1934 Bihar-Nepal earthquake; the August 15, 1950 India-China border earthquake and its aftershock on November 18, 1951. The 1897 Shillong-Plateau earthquake was investigated in detail by Dr. R.D. Oldham who was then the head of the Geological Survey of India. "Report on the great earthquake of 12 June, 1897", Memoir Geological Survey of India (1899), authored by Dr. Oldham, is one of the most well documented and read scientific piece of work in seismology. This earthquake of magnitude 8.7 was felt to distances of up to 1400 km. seriously damaged area had a radius of about 500 km. This also had been the first earthquake, where meticulous observations showed that the accelerations had exceeded 1g. The Kangra earthquake of 1905 was one of the first earthquakes for which an instrumental magnitude of 8.6 was assigned and loss of human lives due to this quake was estimated to be 19,000. However, its epicenter could not be accurately fixed and there were two areas of very high intensity, viz., Kangra and Dehra Dun. The 1934 Bihar-Nepal earthquake was also investigated in detail. This earthquake is known to have created one of the most widely spread soil liquefaction. The slump belt, where almost everything was destroyed, extended to about 200 km in length and about 80 km in width. The 1950 Assam earthquake was located near Rima. Fortunately, it was a remote area and, therefore, not too many lives were lost. The aftershocks continued to occur for more than a year, including an aftershock of magnitude 8 on November 18, 1951.

In addition, several other damaging earthquakes have occurred in the Himalayan region, the recent examples being the Uttarakashi earthquake of 1991 and the Chamoli earthquake of 1999.

Damaging earthquakes have occurred in the Himalayan region in the past, and shall continue to occur in the future too.

The Quiescence of High Magnitude Earthquakes

The earthquake catalogue for the Himalaya and the North-East Indian regions (latitude 20°N to 38°N and longitude 75°E to 100°E), comprising of the Himalaya and the Arakan Yoma Fold Belt for the period 1897 to the present day shows that there had been a total of 14 major earthquakes (M ≥ 7.5) during the period 1897 to 1952. No major earthquake of magnitude 7.5, or larger, has occurred since 1952. There was an apprehension that possibly during the first half of the 20th century, the earthquake magnitudes were overestimated in respect of the Himalayan region. This has been examined in a very detailed study involving re-determining the magnitude of 37 earthquakes of 2 7 in the Himalayan region for the period 1903 to 1985, using seismograms of Gottingen Observatory in Germany (Gupta et al 1995). The re-determined magnitudes of the Himalayan earthquakes were within the error-limits of observation of the earlier magnitude values. This confirmed that indeed no major earthquake of M≥ 7.5 has occurred since 1952. The following table gives the distribution in different magnitudes for the period, 1897 to 1952, and 1953 to 2002:

An examination of the above table shows that while no major earthquake of 7.5, or greater, has occurred since 1952, the number of earthquakes in 6.5 to 7.5 range is comparable.

Magnitude	1897-1952	1953-2002
M > 7.5	14	0
7.5 > M > 7.0	11	8
7.0 > M > 6.5	19	22

This confirms that there is indeed a quiescence of a major earthquake in the Himalayan region (Satyabala and Gupta, 1996). This quiescence has been further confirmed with comparison of other catalogues; for example, those of Abe (1981, 1984 and 1994) and Pacheco and Sykes (1992). As a matter of fact, non-occurrence of a major earthquake for the past 50 years in the Himalayan region has created a false sense of security.

Return Period of Great Earthquakes in the Himalaya

Globally, an effort is being made to determine as to how often major, or great, earthquakes repeat in the same location. Such efforts have been initiated for the Himalaya region also. I would specifically like to refer to one such effort by Seeber and Ambruster (1981) in which from a detailed study of spatio-temporal distribution of earthquakes in the Himalaya region, they have estimated that it takes about 180 to 240 years time for the entire Himalayan Are to rupture. And, the repeat time for a typical magnitude 8 earthquake with a rupture length of 300 km is 200 to 270 years. One drawback of such estimates is the inadequacy of the available earthquake catalogue for the Himalayan region, and the fact that the instrumental data for the Himalaya earthquakes is available only for about last 100 years. For the past three decades, sincere efforts are being made in different parts of the world to identify, characterize, and date the structures deformed by earthquakes, thereby inferring the time of occurrence of past earthquakes. This new field of palaeo-seismology has been very useful in estimating repeat time in several parts of the world. A very sincere effort has been made in the Himalayan region by Sukhija and others (1999) in estimating the return period of great earthquakes along the Chedrang Fault in Shillong Plateau, responsible for the 1897 earthquake. After digging several trenches, very well preserved liquefaction and deformed features were discovered. Using Carbon-14 dating method they found three events of magnitudes comparable to the 1897 event. A return period of 400 to 600 years has been estimated for earthquakes of magnitude 8 or so to recur on Chedrang Fault in Shillong Plateau. Similar work is being now carried out in the vicinity of Bihar-Nepal earthquake of 1936 and Kangra earthquake of 1905.

Earthquake Forecasts

There is a global effort to identify precursors that precede major earthquakes. As of now, a scientifically accepted short time earthquake forecast giving the size, the location, and the time of the earthquake has not been feasible. However, there are a few cases where accurate earthquake forecasts have been made which resulted in timely eviction, saving a large number of human lives from possible death. A classical example is the prediction of Hai-cheng earthquake on February 4, 1975 in China, where timely forecast and eviction saved an estimated 100 thousand human lives from the devastating 7.3 magnitude earthquake that followed. There are some examples of successful medium-term forecasts. One such effort, which was successful for the north-east India region, where, based on precursory earthquakes swarm and quiescence, a forecast was made in 1986. In a very detailed study, Gupta and Singh (1986) observed that major earthquakes in the north-east India region are preceded by seismic swarm and quiescence. However, it is important to recognize swarm and quiescence before the occurrence of the main shock. They discovered one such region in the vicinity of 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, and (2) On the basis of an earthquake swarm and quiescence period, an area bounded by 21°N and 25½°N latitude and 93°E and 96°E longitude, is identified to be the site of a possible future earthquake of M 8±½ with a focal depth of 100±40 km. This earthquake should occur any time from now onwards. Should it not occur till the end of 1990, this forecast could be considered as a false alarm.*" The occurrence of August 6, 1988 earthquake with focal parameters as mentioned below showed that this forecast was true.

In a later study (Gupta, 2001), while analysing this forecast, the following conclusions were drawn: The original study of Gupta and Singh (1986) produced regressions for the estimation of the main shock magnitude and time on the basis of swarm magnitude, raising it above the purely anecdotal level. In the field of earthquake precursor studies, for most of the precursors there are no regressions, as yet.

The main shock magnitude lies well within, and the precursor time a little outside, the 95percent tolerance levels of the regressions of Gupta and Singh (1986).

Earthquake	Forecast	Occurrence
Parameters	Gupta and Singh, 1986	NEIS (Preliminary Determination)
Epicenter	21°N to 25½°N	25.149°N
	23°E to 96°E	95.127°E
Magnitude	8+½	7.3
Depth	100+40 km	90.5 km
Time	February 1986 to December, 1986	August 6, 1988 (00.36.26.9G.C.T.)

The main shock magnitude and precursor time lay close to published regressions for precursory swarms in other countries. The generalized precursory swarm hypothesis developed by Evison (1982) states that a cluster of (one or more) swarms is precursory to a cluster of (one or more) mainshock events. Therefore, the January 5, 1991 earthquake of M = 7.3, falling within the identified area of the forecast, is equally relevant as it forms a cluster with the August 6, 1988 earthquake. The encourages success similar investigations elsewhere in the Himalayan Frontal Arc for concentrating hazard related work in a few critical areas. It may also be mentioned that certain precursory patterns were observed before the Uttarkashi as well as Chamoli earthquakes in the Himalayan region.

How Damaging will be the Future Earthquakes?

Increase in the population density in the foothills of the Himalaya during the last several decades has increased earthquake risks several folds. The situation is further worsened with dispensation of wooden houses, and concrete structures coming up in these areas. These two factors, increased population and poor construction has been pointed out by Arya (1992), when he estimated the damage scenario in the region in the event of a repeat of the Kangra earthquake 1905. In his analysis, he presumed that the distribution of earthquake intensity will be similar to the 1905 earthquake, covering areas of 500 sq km, 2400 sq km, and 5,000 sq km under intensities X, IX and VIII, respectively on the Modified Mercalli Intensity Scale. Keeping in view the building material and construction in these areas, it is estimated that approximately 1,45,000 houses will collapse completely and another 2,67,800 houses will suffer severe damage. Depending upon the time of the day when earthquake occurs, loss of human lives would vary between 88,000 and 3,44,000, as given in the table below. Arya has underlined the importance of retrofitting the important buildings to reduce hazard.

Global Seismic Hazard Assessment Programme

The growing realization that many of the world's biggest cities are at risk due to ground shaking from near or far earthquakes places higher emphasis on long-term seismic hazard assessment. In a very broad sense, hazard assessment involves putting together information on: (a) earthquake sources, (b) expected ground shaking, and (c) site response due to local geological conditions. The Global Seismic Hazard Assessment Programme (GSHAP), which involved about 500 scientists from all over the world and completed over a period of seven years (1992-1999) was one such endeavour, which has generated data that forms the basis of seismic hazard assessment in several regions (Giardini, 1999; Giardini & Basham, 1993).

A project of the scientific and technical committee under INDAR (International Decade of Natural Disaster Reduction), GSHAP may be regarded as the first global step towards the implementations of earthquake risk reduction strategies. Coordinated at a global level and implemented at regional and local levels through a number of regional centers, it has combined a variety of data that form essential inputs for hazard assessment. Each regional center was concerned with a defined geographical territory and had to deal with four main components of seismic hazard assessment: (1) preparation of unified and homogeneous earthquake catalogues, (2) seismotectonic and earthquake source delineation, (3) strong motion studies and finally, (4) computation of predictive seismic hazard. Final products of GSHAP are available as reports and research articles (see Annali Di Geophisica Vol. 42, No. 6, December 1999 and also visit: seismo.ethz.ch/GHSAP/).

Time of Occurrence	Deaths in Collapsed Houses	Deaths in Part-Collapsed Houses	Total Potential Deaths
Midnight (Sleeping)	40%	20%	3,44,000
Morning (Awake and Sleeping)	20%	10%	1,77,000
Noon Time (outdoor working)	10%	5%	88,000

Probabilistic seismic hazard maps prepared as a part of the GSHAP show contours of maximum peak acceleration that would be exceeded by 10% probability in a given time window, say 50 years. Although this would give a fairly good idea of the long-term regional seismic hazard, it does not reflect the effects of attenuation/amplification of seismic waves due to local, site-specific variations. Thus, it becomes necessary to identify individual areas, based on their potential for hazardous earthquake effects, which is the concept behind microzonation. In essence, it involves identification of seismic sources, mapping of potential faults, and the study of soil characteristics, and finally integrating them to characterize the hazard at a scale, suitable for appropriate building practices. Countries, like the United States, have made significant progress in developing microzoning, or shaking intensity maps, that are used in hazard/risk assessment (visit www.abag.ca.gov/bayarea/eqmaps/to view shaking intensity maps for the San Francisco Bay area).

Recognizing the threats faced by most cities from nearby or far away earthquakes, more countries are preparing microzoning maps and GIS-based information packages for disaster mitigation and post-disaster management. Recently, a detailed GSHAP map has been prepared for India (Kumar and Bhatia, 1999).

Microzonation as a Next Step

After having prepared seismic zoning maps for the country, the next step is preparation of "microzonation maps" for major cities. One such extensive exercise has been carried out for the Jabalpur region, where scientists from Geological Survey of India, National Geophysical Research Institute, India Meteorological Department, and several other universities and institutions have done a commendable job of preparing a detailed seismic micro-zoning map of Jabalpur region. In this interesting study, four levels of microzonation has been carried out which consist of:

- base level geo-scientific microzonation,
- microzonation with geo-technical inputs on ground characterization,
- microzonation improvised with parameters on site effect and ground response, and
- seismic risk microzonation with engineering and geological inputs.

In this exercise, the entire Jabalpur region has been divided into 62 micro-zones and a detailed analysis has been conducted. The construction in the region has been classified into three categories: Type A consists of 15 per cent of construction, which are basically non-engineered structures and are likely to fail during earthquakes generating intensity VII or more on MM scale. The second category Type B has 70 per cent buildings. These are basically buildings consisting of ordinary bricks, half-timbered structures etc. 84 per cent of these buildings are likely to suffer in form of excessive cracking, falling of walls etc., when subjected to intensity VII or more. The Type C includes the remaining 15 per cent of buildings, which are designed to take care of vertical building loads. However, no care has been taken for horizontal loading and 45 per cent of these buildings are estimated to be unsafe and suffer from excessive cracking, diagonal cracking, etc. In this map, seismic damage scenario of Jabalpur urban area has been presented taking into account construction practices, material of construction, quality of construction, type of buildings as well as geological and geo-technical parameters. Finally, this exercise has provided zone-wise vulnerability of different types of buildings. The outcome of this study is also provided on GIS-based soft copy as well as hard copies (Agarwal and Chourasia, 2003, Mishra, 2003). It is necessary to make similar efforts in other parts of the country.

A mention may also be made of a microzonation effort carried out for Sikkim by S.K. Nath and others (2000) by making use of Strong Motion Network in Sikkim comprising of nine accelerographs, and over 50 well recorded seismic events during the period 1998-2002. They have integrated the geological (soil class, class, lithology, and landslides) and seismological (site response, peak ground acceleration and resonance frequency) attributes to generate a microzonation map of Sikkim.

Efforts have also been made for Delhi region to prepare a soil liquefaction map. Assessment of potential liquefaction is an extremely important element in microzonation. Using the data from 1200 bore holes, Rao and Mohanty (2002) have prepared a soil liquefaction map for Delhi, dividing it into regions of severe, moderate and minor liquefaction inputs used for preparing this map include data on depths to various layers, type of soil, unit weight, values from standard penetration test (SPT), thickness of the overburden depth of the water table. The study has been useful in identifying vulnerability of locations to liquefaction and the estimating the safety factor.

Ground motions in Delhi from future large/great earthquakes in central seismic Gap of Himalaya have been estimated for a large / great earthquake located some 200 km from the Delhi region (Singh et. Al, 2002). The expected accelerations are given in below tables.

Expected acceleration of earthquake MW = 8.0; Distance = 200 km

		Amax	Vmax	Dmax
Soft Sites	Horizontal	50 – 60 gals	5 – 13 cm/s	4 – 9 cm
	Vertical	25 – 40 gals	6 – 8 cm/s	5 – 9 cm
Hard Sites	Horizontal	10 – 12 gals	3 – 7 cm/s	4 – 9 cm
	Vertical	5 – 8 gals	3 – 4 cm/s	5 – 9 cm
MW = 8.5				
Soft site				
Distance = 200 km				

Expected acceleration of earthquake

Study	Amax	Vmax
Singh et. al., 2002	100 gals	15 cm/s
Khattri et. al., 1999	200 gals	30 cm/s

GPS observations

From the operation of 24 GPS Observation points in Nepal, India, and Tibet during the period 1991 through 1995, a maximum horizontal southward velocity of 17.5±2 mm has been estimated between Southern Tibet and India. There is almost nil motion between Indo-Gangetic plain and Bangalore. The GPS-derived horizontal strains are found to be 226X10º for Peninsular India and 2X10" for the Himalaya. In one of the interesting studies by Bilham et. al., (2001), it is pointed out that India and southern Tibet converge at a rate of 20 ± 3 mm/year. Eighty per cent of the resulting strain is absorbed in a 50 km wide region centered on the southern edge of Tibet Plateau. The remaining 20 per cent of strain is absorbed in surrounding Himalaya. This results in a convergence of 2 m per century. Under southern Tibet and further north, detachment slips seismically. Assuming that process of strain accumulation is linear in time and almost uniform along the Himalayan plain, Bilham et. al. (2001) argued that most segments except those that rupture during 1905, 1803, 1934 and 1950 earthquakes have not ruptured in the past 500 to 700 years and these segments, numbering 6, of length 200 to 250 km are associated with potential slip exceeding 8 to 10 meters thereby, making them possible future sites of levelling great earthquakes. The analysis of levelling and GPS data from the Himalaya suggest that strain accumulation is underway in several segments. However, we do not know the phase of strain and accumulation at present. Another problem is that we do not have a direct and reliable estimate of slip that occurs in any of the great earthquakes of the Himalaya. Further, the available earthquake catalogue is of too short duration and incomplete to estimate the potential slip for the mapping great earthquake in each segment that has accumulated since lost earthquake. All these measurements, nevertheless, do indicate seriousness of the problem.

Levelling

India has a very old tradition of establishing benchmarks by Survey of India and investigating changes in level with the passage of time. A number of reports have been generated by the Survey in this connection. Here, I would specifically like to mention of a couple of studies by Gahalaut and Chander (1997 a & b). In an interesting study, Gahalaut and Chander observed that a levelling line along the Saharanpur-Dehradun-Mussoorie highway crosses the northwest Outer Himalaya. This line has been surveyed from time to time since 1861. This revealed that there was a co-seismic uplift along the line caused by great Kangra earthquake of 1905. However, later on, most of the benchmarks have started subsiding in the decades following 1905 earthquake. This has been inferred as evidence that the upper crust along and adjoining the level line experienced a cycling process of strain accumulation and release associated with great earthquakes. In another interesting study, Gahalaut and Chander (1997, b) investigated ground elevation changes in Nepal Himalaya based on repeat levelling observations between 1977 and 1990. With certain assumptions, they conclude that the plate boundary fault that ruptured during 1934 Bihar-Nepal earthquake may be currently locked up and the hanging wall rocks may be experiencing down dip drag. Assuming down dip rupture of 50, 100 and 150 km associated with the 1934 earthquake values of 12, 14 and 18 mm per year of convergence are obtained. These values compare favourably with the estimated long-term average 18±7 mm per year for plate convergence accommodated at Himalaya.

Conclusion

I have broadly stated the current status of knowledge about earthquakes in the Himalayan region. Earthquake prediction is not yet possible. But the areas most likely to be affected by earthquakes and the kind of damage that would result are broadly known. To reduce the vulnerability of citizens in the Himalayan region from earthquakes – Implementation of building codes of BIS be made mandatory, Retrofit important buildings, situated in zone IV and zone V of the Zonation map, Seventy per cent of Indians live in rural areas in houses and dwellings made without any engineering considerations. Methods are available to strengthen their dwellings by some simple, very inexpensive approaches. These should be popularized, Microzonation of important cities of the country is a must, Equally important is to make public aware of what to do and what not to do before, during and earthquakes. Suitable training of high-school level would considerably help us in addressing the problem of earthquakes in the Himalayan region.

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