Lineament Tectonics - Its Relation to Seismic Activity in India

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Abstract

Structural changes in the earth's crust develop continuously due to a slow and gradual movement of an overstressed part of the earth. These changes normally termed as tectonic plates are formed due to their ultimate relationship to the development of the structure of the earth. Volcanic activity, ground subsidence and tectonic stresses all set up strong motions Tectonics is responsible for almost all the world's earthquakes and geological faulting Impacts of earthquakes on the buildings normally depend upon Magnitude, Duration, and Acceleration of the strong motion of the ground and vulnerability of buildings. The Indian subcontinental plate, after getting detached from its Gondwanic partners in the early Cretaceous, moved very rapidly subducting underneath Asian and Burmese plates followed by a collision resulting in the episodic lift of the Himalayas

Seismotectonic Divisions of India

India has two broad seismotectonic divisions, one of the Peninsular region comprising relatively stable continental shield and the other of the extra-Peninsula including the plate margins, the Tertiary Orogenic Belt and the peripheral foreland. The latter one constitutes one of the world's most active seismic domains essentially under compressive stress field.

Extra- Peninsula

The Himalayan region in general and Northwest Himalayas in particular have been divided into following NW - SE trending linear belts, has identified five discrete crustal belts displaying similar seismic attributes

i) Main Himalayan Seismic Zone
ii) High Himalayan Seismic Zone
iii) High Plateau Seismic Zone
iv) Kashmir Syntaxial Seismic Zone and
v) Foot Hill Seismic Zone

The zone responsible for most of the seismic activity in the Himalayan Region is the main Himalayan Seismic zone displaying mainly thrust type sources (Narula, 1991). This zone could be further subdivided into blocks by transverse fault systems.

Similarly, significance of transverse lineaments in the Seismotectonics of Eastern Himalayas and its fore deep and Burmese arc brought out by Mukhopadhaya (1992). Among the prominent active lineaments are Tista, Gangtok, Kopili, Bomdila, Padma, Madhupur and Sylhet lineaments. Kopili lineament fragmenting the Shillong and Mikir - Massifs is conspicuously developed and is quite active.

Seismicity and Stress Fields in Extra-Peninsula

The Himalayas in the last 200 years, have recorded over 650 earthquakes of magnitude 5 and above. The tectonic stress fields in the Himalayas and adjoining regions have been found to be highly variable. The orogenic belt and influenced neighbouring areas can be divided into the following major stress regimes

i) Hindu Kush
ii) Frontal Arc
iii) North Eastern Himalayas
iv) Arakan - Burma
v) Tibetan Plateau

i) Hindu Kush: Strike slip and thrust mechanisms have been observed to be the dominant style of deformation. The seismicity in this regime has been considered to be along Herat fault, Chaman fault and the mountain ranges in the Pamir Knot. The largest earthquake of magnitude 8 occurred on 21 October 1907 and 7th July 1909.

ii) Frontal Arc: Focal mechanism of most of the earthquakes of Frontal Arc show thrust faulting, though rarely strike slip mechanism has also been obtained. Ni and Barazangi (1984) suggested that all large earthquakes occurred between the MCT and MBT with the compression in N-S to NNE - SSW directions The Frontal Arc can be divided into broad seismo-tectonic domains of Kashmir - Himachal, Garhwal - Kumaon - West Nepal and Nepal - Sikkim

In the Kashmir-Himachal unit the earthquakes are generally shallow focus except in the Western fringe. The strongest earthquake was that of 4th April 1905 of Magnitude 8 in Kangra. The rupture of the Kangra earthquake extended in the detachment under the lesser and outer Himalayas and parts of Indo gangetic plains The other destructive earthquakes of the region are 1885 Srinagar (M = 7.5), 1906 - Sundernagar (M = 7.5), 1929 - NW India (M = 7.1), 1945, 1947 Chamba earthquakes (M= 6.5, 6.2) and 1975 Kinnaur Earthquake (M = 6.2) The last one showed normal type of faulting with nodal plane corresponding with Kaurik fault

In the Garhwal - Kumaon - West Nepal unit, the earthquakes are generally of shallow depth with thrust type focal mechanism The strongest earthquake was that of 28th August 1916 of magnitude 7 5. The other damaging events were 1958 Kapkot earthquake (M = 6 0), 1980 Dharchula Earthquake (M = 6 1), 1991 Uttarkashi earthquake (M = 6.6) and 1999 Chamoli Earthquake (M = 6.8)

Uttarkashi Earthquake

The earthquake (Mb 6.6) which struck in the early hours of 20th October, 1991, in Uttarkashi area and rocked the whole of Garhwal and adjoining parts of the Kumaon Himalayas took a toll of 768 human lives and injured 5066 persons. The wide spread devastation was marked by severe to partial damage to about 0 1 million houses spread over an area of about 2400 Sq. km, numerous landslides and ground fissures. The cause of the event is attributed to strain unlocking at a depth of about 12 km, at the intersection of a fault located south of the surface trace of MCT and the detachment surface.

Indo-Nepal Earthquake

This earthquake (m 5.5), which occurred in the afternoon of 5 Jan.1997, jolted the Dharchula area of Pithoragarh district and neighbouring districts of Baitadi and Dharchula, in Nepal. The macroseismic survey revealed that the epicentre of the event lay in the area located around 15 km NE of Baitadi town in Nepal The event whose severest effects were partial collapse of non load bearing walls, of some poorly build structures, was inferred to have originated at a depth range of 16 to 19 km due to rupture along a fault trending in NE-SW direction.

Another event in the same area known as Dharchula - Bajang (Nepal) earthquake of July 29, 1980 with a magnitude of 6.1, was also inferred to have been caused by the rupture along NE-SW trending fault.

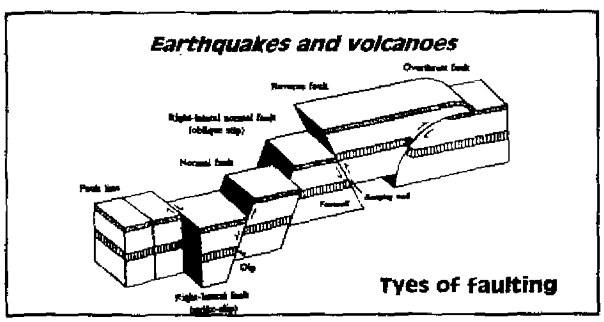
Chamoli Earthquake

The 29th march, 1999 earthquake is the most destructive seismic event in recent times in the Garhwal region. The Mb 6.8 event, which struck at 0035 hr. in Chamoli district, was felt as far as in Delhi, Himachal Pradesh and other Northern State of India. Although a bigger event than the Uttarkashi Earthquake, it caused comparatively lesser destruction in the form of 103 human casualties, injuries to about 395 persons, severe damage to buildings mainly confined to Chamoli town and other isolated villages located east and west of it.

The fault plane solution and the trend of meisoseist indicate a general E-W trending faults/ Lineaments as the causative surfaces.

In the Nepal - Sikkim Unit, the 1934 Great Bihar - Nepal earthquake of M = 8.3 occurred that took a toll of 9040 human lives and brought conspicuous terrain changes. The same region was again rocked in 1988 by a 6.4 magnitude earthquake. The épicentral tract of the two events lie close to east Patna fault, south of the surface trace of MBT.

iii) **North Eastern Himalyas :** During the past 100 years, twelve shocks of magnitude[3], seven have been recorded in this region. The region has three distinct units Assam Syntaxis, Shillong Plateau and Arakan Burman ranges. Tectonics and stress distribution in the northeastern part of Himalayas are complicated because of convergence of the Himalaya and E-W convergence of the Indo Burman ranges. The stress distribution is therefore highly heterogeneous
The Assam syntaxis is a complex domain, where several



large earthquakes, including the 1950 Great Assam Earthquake (M = 8.7) have occurred Focal mechanism generally show strike slip and thrust type deformations. Tributaries of the Brahmputra river - particularly Subansiri, Dibang and Tiding were blocked by coseismic landslides, which on bursting caused considerable loss of life and property.

Shillong plateau has been described as the only topographic expression of the collision in the shield area, further south of Himalayas. The great Assam earthquake of 1897 (Mb = 8.7) occurred in this unit. This is the greatest earthquake ever documented.

iv) **Arakan-Burma :** The Indo-Burman ranges mark the northward continuation of Andaman Nicobar Arc where the Indian Ocean floor is subducted beneath the southeastern Asian countries. The focal mechanism of the earthquakes are predominantly thrust or strike slip type with a few normal fault solutions at intermediate depth. The strongest earthquake of the region (Mb = 7.3) occurred in 1988.

v) **Tibetan Plateau :** Most of the seismicity of this trans Himalayan zone is confined to shallow crustal depths of 5 - 10 km, though isolated events occur at depth of even 80 km. The plateau is in a general slate of extension.

Peninsular Shield

In the evolutionary history of the Indian Peninsula extending over three billion years, the drifting of shield fragments, opening and closing of the oceans, Orogenic movements, development of the mobile belts and extensive rifting are some of the important tectonic phases.

Seismicity of the Peninsular Shield

The ancient shields are generally stable except for the continental margin, rift zones and faults present in the continental crust. Thus the Peninsular India had been considered as a region of slight seismicity. The Koyana earthquake of 1967, changed the long held image of the region and led to the revision of the seismicity zoning map of India, which draws heavily on the historical and recorded incidences of earthquakes and their relationship with the tectonic framework. More recent earthquakes in Latur, Koyana, Khandwa and Jabalpur necessitated complete rethinking on the subject.

The damaging earthquakes of the peninsular region exceeding magnitude 6 include the events of Bombay - 1618(I=X), Samaji-1668 (I=X), Kutch-1819 (M=7.8), Sone valley -1927 (M=6.5) , Satpura-1938 (M=6.3), Anjar 1956 (M=6.1), Koyana-1967 (M=6.3), Killari -1993 (M=6.3) and Jabalpur - 1997 (M=6.0).

A correlation of the seismicity patterns with the tectonic framework of southern Peninsula has brought out the following inferences (Project Vasundhara, 1994)

1. Clusters of epicentres between Mysore and West of Pondichery is located close to Dharwar Craton - Pandyan mobile belt and the cluster occurring east of Mangalore is probably related to the west coast of the fault systems.
2. The cluster of epicentre including the famous Bellary earthquake- 1843 (I=VII) are related to the Chitradurga boundary thrust and other lineaments, marking the eastern and western margin of the Closepet Granite.
3. Clusters of earthquakes in Ongole area has been related to NNW, NW and NE lineaments and those of Chittoor and Cuddapah to a major system of E-W faults.
4. Many isolated incidents have been related to Crystalline - Sedimentary boundary faults, Kerala lineament and other fault systems.

The concentration of the epicentres in the Central Peninsula are confined mainly along the SONATA and Sahyadri belts and Godavari graben. The important earthquakes of the SONATA zone include the Son valley - 1927, Satpura- 1938, Balaghat - 1957, Broach- 1970 and

Jabalpur 1997. The major earthquakes of the Sahyadri belt include that of Bombay -1618 and 1856, Mahabaleshwer - 1964, Koyana -1967 whereas that of Godavari Graben is Bhadrachalam-1969.

In the western part, clustering is mainly along Cambay graben and Rann of Kutch with the former accounting for earthquakes of Surat - 1864, Mount Abu- 1848,1882 and the latter that of Samaji - 1668, Kuthch 1819 and Anjar - 1956.

In the eastern part important earthquake events associated with Mahanadi graben and other fault systems include that of Bankura -1969 and Ganjam - 1837, etc.

Some recent damaging earthquakes of the Peninsular region are described as follows:

Koyana Earthquake

Considered as one of the big events of the shield area, the Koyana earthquake (Mb = 6.3) of 10th December, 1967. The earthquake claimed over 200 human lives and injured over 1500 people. It also damaged more than 80% of the houses in Koyana Nagar Township. Over100,000 shocks of varying magnitudes have been recorded in the Koyana region in the last 25 years.

Studies have related the origin of the event with seismogenic displacement along conjugate faults - one with strike slip motion and other with normal faulting.

Killari Earthquake

Billed as one of the deadliest earthquake of the shield area, the Killari event (Mb 6.3), which struck in the early hours of 30th September 1993 left behind a long trail of destruction including death of 7446 people, injuries to 14845 persons and severe to partial damage to 37009 houses.

The post earthquake studies have indicated this to be a shallow event (depth 6 km) caused by displacement along intersecting faults having orientations along N60°E - S 60° W (Strike Slip type) and NW-SE (Reverse type), respectively.

Jabalpur Earthquake

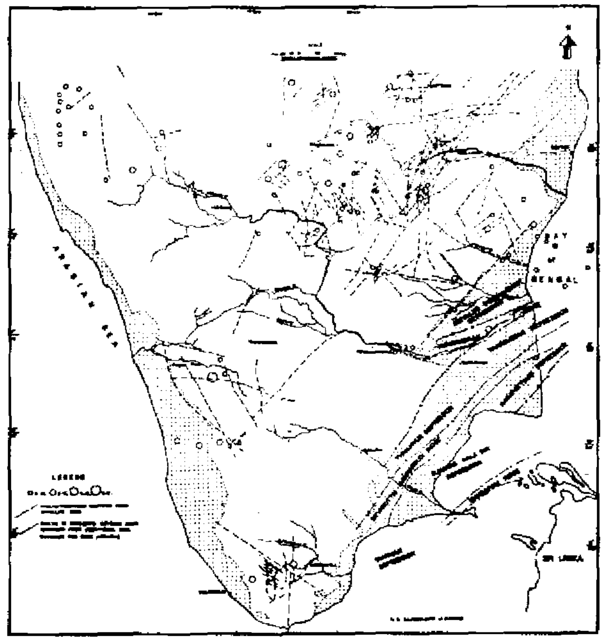
One of the major damaging events of shield area of recent times, is the 22nd May 1997 Jabalpur earthquake of M 6.0 The event left about 40 people dead and wide spread destruction in and around Jabalpur town. The heaviest damage was in Kosamghat village, located about 10 km Southeast of Jabalpur town, where almost all of its 115 dwellings were either razed to the ground or were rendered uninhabitable.

The studies indicated earthquake to be related with the tectonically active ENE-WSW trending Narmada-Tapti rift zone.

Earthqukae Disaster Mitigation

Earthquake occurrence is a natural phenomenon. It occurs suddenly and without warning for which reliable prediction is not yet possible.Studies have revealed that the effects of most of the natural disasters can be mitigated/ reduced by preventive actions which are least expensive. To make a house collapse proof in an area likely to be affected by a hypothetical 8.0 magnitude earthquake, it will cost 4 to 6% extra expensive if earthquake resisting measures are taken during construction stage and it may require 15 to 25% extra cost if it is seismically retrofitted after construction. If nothing is done at any time for earthquake resistance, they house may have to be reconstructed altogether. (Arya,1992)

Earthquake disaster reduction is a possibility by preventive engineering measures. Construction codes to withstand tremors in specified area may be evolved and strictly enforced. Disaster planning and relocation of settlements may be undertaken using photogeological, remote sensing, geotechnical and geophysical data. Simple methods of making buildings earthquake resistant need to be illustrated with models, and awareness for the same has to be increased. Earthquake resistant community centres, where people could gather in large numbers, in case of a calamity should be built, at proper sites.



Earthquake-prone fractures of Southern Peninsular

References

Acharyya S.K. (1997) : Tectonic Evolution of the Indo-Burma Andaman Mobile belt and nature of its linkage with the Indian continent. Sixth Prof. Jhingran Memorial Lecture, under the auspices of the Indian Geological Congress.

Arya, A.S. (1992) : Possible effects of a major earthquake in Kangra region of Himachal Pradesh. Cur. Sci. vol. 62 No. 1& 2.

Harsh. K.Gupta et, al.(1993) : Investigation of Latur Earthquake of Sept. 30, 1993. Geol. Surv. Ind. Spl. Pub. No. 27.

Mukhopadhyay, M. (1992) : On earthquake focal mechanism studies for Burmese Arc. Cur. Sci. vol. 62.

Molnar, P. (1990) : A review of the seismicity and the rate of active thrusting and deformation at the Himalaya. Jour. Him. Geol. Vol. I (2).

Molnar, p. and Tapponnier, P. (1975): Cenozoic tectonics of Asia : effects of a continental collision. Science vol. 199.

Narula, P.L. (1991) : Seismotectonic evolution of northwest Himalaya. Unp. GSI, Report.

Narula, P.L., Kayal, J.R., Pande, P., Gupta S.K., Venkataraman N.V., Maran, N. and Harendranath L. (1996) : Geotectonic setting and seismicity of the area, Killari Earthquake GSI spl. Pub. No.37.

Ni J. and Barazangi M., (1984) : Seismotectonics of the Himalayan collision zone : geometry of the underthrusting Indian plate beneath the Himalaya. Jour. Geophy. Res. Vol. 89.

Pande, P., Gupta S.K., Harendranath L., Venkataraman N.V., Maran, N. (1995) : Damage patterns and delineation of isoseismals of Killari earthquake of 30th Sept. 1993. Geol. Surv. Ind. Spl. Pub. No.27.

Radhakrishna B.P., and Naqvi S.M. (1986) : Precambrian continental crust of India and its evolution . Jour. Geol. Vol. 94.

Rajurkar, S.T., Bhate, V.D. and Sharma S.B. (1990) : Lineament fabric of Madhya Pradesh and Maharashtra and its tectonic significance. G.S.I. Spl. Pub. No.28.

Rastogi, B.K. (1981) : Fault plane solutions and tectonics of Himalaya. GSI. Mis. Pub. No.41 Part IV.

Seeber, L., Armbruster J.G. and Quittmeyer R.C.(1981) : Seismicity and continental subduction in the Himalayan arc. Am. Geophy. Union. Vol. 13.