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Earthquake hazard

Earthquakes caused more than 70,000 death in India since the beginning of its recorded history. The Himalaya mountain is particularly vulnerable to high seismicity; so is the vast stretch of the plains fronting the mountain arcs where more than 40% of the Indian population lives. The 1897 Meghalaya earthquake laid waste 3,80,000 km^2 area and killed more than 1600 people in that sparsely populated region. The 1905 Kangra event caused more than 19,000 deaths. The devastating 1991 Uttarkashi earthquake in a seismically 'quiet' central sector is fresh in our memory. Recent earthquakes in the Latur (1993) and Jabalpur (1996) areas in the heart of the 'stable' Peninsular Indian Shield, where strain is accumulating but at an extremely slow rate (nearly 0.01 μstrain/year compared to more than 0.5 μstrain/ year in the Himalaya), have forced us to take stock of the situation afresh and evolve appropriate strategy for coping with the hazard. With this aim in mind, the Wadia Institute of Himalayan Geology organized a two-day Indo-US Workshop on Palaeoseismicity with Special Reference to Seismic Hazard in the Himalaya, on March 27 and 28, 1997. Two of the papers presented (Bilham *et al.* and Yeats and Thakur) appear in this issue.

Earthquakes occur when the crust ruptures and the broken blocks slip past one another or move sideways or up-and-down along faults. It is, therefore, critical to identify and delineate faults that have been active in the geologically recent past or are currently active as manifest in imperceptibly slow movements (creep), dislocation of rivers and lake-deposits, disruption of drainage, modification of landform, etc. Micro-seismicity delineates zones of continuing movement underground. Global Positioning System (GPS) geodesy now provides a very powerful and precise method of measuring rates of movements on active faults and estimating continuing strain buildup. Present polar motions are measured daily by continuous GPS receivers located at Bangalore (in the Indian Institute of Science campus) and in Asia to mm/year precision. Roger Bilham *et al.* (**page 213**) demonstrate that the Indian plate is converging towards Asia at the rate of 58 ± 4 mm/year, it has advanced beneath Tibet across the Nepal Himalaya at the maximum rate of 17.7 ± 2 mm/year and is causing crustal shortening and resultant uplift at the rate of 5 to 8 mm/year. There is a slip deficit of 13 ± 8 mm/ year beneath the Nepal Himalaya, this being converted into elastic strain which generates earthquakes. Since moderate earthquakes do not occur sufficiently frequently to accommodate the observed convergence of India and Asia, there is progressive buildup in what are recognized as seismic gaps – where the crust is locked to its base. It is the great earthquakes (of magnitude $M \geq 8$) that can adequately relax the accumulated strain. The identified seismic gaps are thus sites of future earthquakes of great magnitude. Bilham *et al.* show that nearly 80% of the convergence field is confined to a narrow belt no more than 100 km wide, and that 50% of the field has within a 50 km wide zone despite the surface strain extending 200 km from the Great Himalaya (Himadri). In this narrow belt of deformation and maximal strain accumulation and faster uplift rate (7 ± 3 mm/year) there is transition between the Indian plate sliding under Tibet and it being stuck or locked. It is at a depth between 15 km and 25 km. It is this narrow transition zone where intensive seismological studies need to be focused, for it is the locked part where strain is progressively building up and which will eventually be relaxed by earthquakes whose magnitude cannot be less than M 8.

It may be mentioned that even where creep is taking place, earthquakes would occur; the creeps delay the occurrence of earthquakes but do not prevent them from happening. The frequent occurrence of moderate events would thus increase the time between great events by reducing the amount of slip.

Assessing the seismic hazards in the zones of tectonic boundaries between Himalaya and Indian shield and between Great Himalaya and Lesser Himalaya, R. S. Yeats and V. C. Thakur (**page 230**) demonstrate that beneath the Great Himalaya (Himadri) where the gently dipping (6 ± 3°N) plain of detachment (MHT) steepens to 10°–25°N in a sort of ramp, the seismicity is very high. Here the axial surface of the fault-bend fold – a sharp kink – is active at crustal scale, so that the uplift rate is higher and occurrence of intermediate-size earthquakes quite frequent. These add to the strain on the flat (of the MHT) to the south which is completely locked and thus trigger slip which ruptures all the way to the Himalayan front. The flat plane (of MHT) ends up in a series of fault propagation folds (described as Himalayan Front Fault), where the seismicity is quite high.

The central seismic gap between the 1934 Bihar–Nepal earthquake and the 1905 Kangra event was struck by earthquakes in 1803, 1810, 1826, 1833 and 1866, but they could not release the accumulated strain. There will be more earthquakes of $M \geq 8$ in the near future in the seismic gap embracing eastern Himachal, Kumaun and Western Nepal, assert Yeats and Thakur. The Jammu gap west of the Kangra event, is equally vulnerable to a mega event, for this sector has not been ruptured by great earthquakes since the AD 25 Taxila event.

Needless to state, there is an urgency in carrying out neotectonic-palaeoseismic studies to determine the recurrence intervals and in establishing GPS arrays in the seismic gaps to measure strain buildup and slip rates.

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