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REGIONAL SEISMIC HAZARD AND RISK ASSESSMENT FOR NORTHEAST INDIA AND BHUTAN

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The region of Northeast India including the territory of Bhutan is located in the centre of the Himalayas in one of the seismically most active zones in the world (Bora and Baruah, 2012) with the remarkable exception of the Assam Gap (Khattri et al., 1983). During the last 200 years, 20 earthquakes with magnitudes 7 or larger (Kayal et al., 2006) occurred in the region, the most severe ones being the 1897 Shillong earthquake (M_W 8.1, Bilham and England, 2001) as well as the 1950 Assam earthquake (M 8.7; Tillottson, 1953).

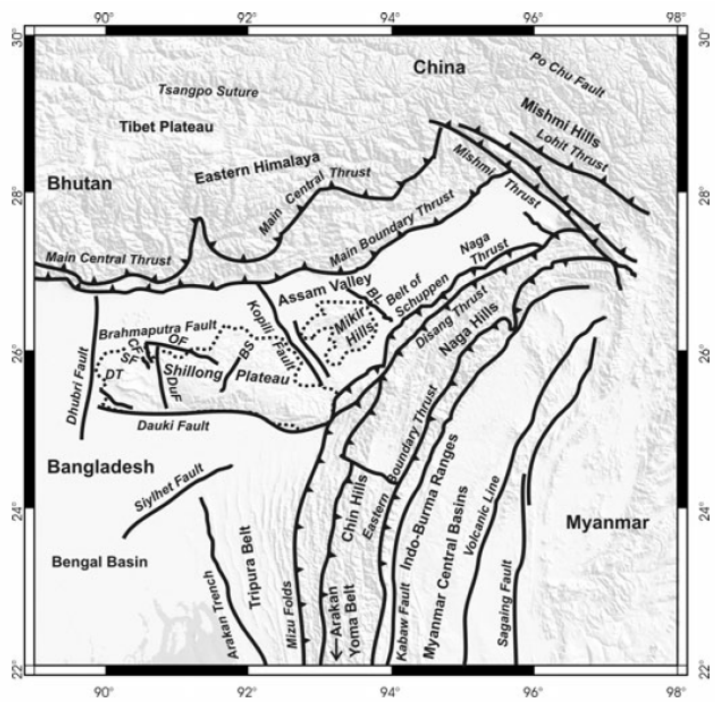

Figure 1. Tectonic setting of Northeast India and surrounding regions (figure taken from Angelier and Baruah, 2009). Major thrusts as thick lines with triangles on the upthrust side. Other major faults as simple thick lines. Boundaries of the Shillong and Mikir plateaus are marked by dotted lines. Geological names in italic, geographic names in roman characters. Names of main faults and thrusts indicated, with some abbreviations in the western Shillong Plateau (DT, Dapsi Thrust; DuF, Dudhnoi Fault; OF, Oldham Fault; CF, Chedrang Fault; SF, Samin Fault, BS, Barapani Shear Zone) and eastern Mikir Plateau (BL, Bomdila Lineament).

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Both earthquakes resulted in extensive destruction; the 1897 Shillong earthquake led to 1,540 fatalities and a property loss of 30 million USD (Tillottson, 1953), whereas the 1950 Assam earthquake caused 1,532 fatalities on the Indian side (Nandy, 2001). However, a rapidly increasing population density and the recent large developments of infrastructure alarmingly increase the vulnerability of Northeast India to damaging earthquakes (Ragukanth, 2008).

Tectonicwise, the considered area is very complex (Figure 1). It is situated at the convergence zone between three major tectonic plates, namely the Indian, the Eurasian and the Sunda plates. It is further jawed between two major mountain ranges: the Himalayan arc to the north and Indo-Burmese arc to the east meeting at the Assam syntaxis in the Upper Assam valley (Angelier and Baruah, 2009). It is bounded by major, all India-verging thrust zones (the MBT and MCT to the north, the Lohit and Mishmi thrusts to the northeast, the Naga, Disang and Eastern Boundary thrusts to the east and the front thrusts of the Arakan Yoma Belt to the southeast; Angelier and Baruah, 2009). Geodesy studies conducted since 1995 indicate that the rates of north-south convergence between the Indian craton and the Himalayas are in the order of 10-15 mm/a (Jouanne et al., 2004).

The highest rates of seismicity generally occur in the Indo-Burmese arc as well as the Shillong-Mikir plateau (Baruah, 2008; see also Figure 2). But whereas the seismicity in the Himalayan belt tends to be rather shallow, since it results from continental-continental collision, the ongoing subduction in the Indo-Burmese arc results in intermediate to deep focus earthquakes (Verma *et al.*, 1976).

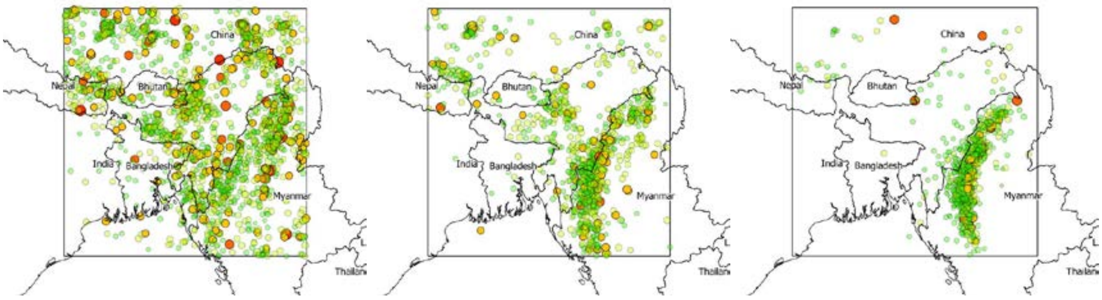

Figure 2. Events within the considered region recorded in the ISC reviewed bulletin; left: 0-45 km depth, middle: 45-90 km depth, right: depth > 90 km; events coloured according to magnitude (green: $M_W < 4$, yellow: $4 < M_W < 5$, light orange: $5 < M_W < 6$, orange: $6 < M_W < 7$, dark orange: $7 < M_W < 8$, red: $M_W > 8$)

A further fact that may serve as an indicator for an increase in vulnerability is the current ambitious program for development of hydropower installations, especially in Bhutan. Since Bhutan does not yet has a final and officially approved seismic hazard zonation map, high uncertainties and controversies exist with respect to the enforcement of a national seismic building code and, more importantly, the applicability of the codes of neighbouring countries while extrapolating their seismic zonation maps (as e.g. applying the nearest earthquake zone of the Indian zonation map; BIS, 2002).

In the course of the Indo-Norwegian collaboration project EQRisk, efforts are concentrated on a regional seismic hazard analysis for the entire region of Northeast India including the territory of Bhutan as well as damage and loss assessment studies for selected test bed cities in the region. The hazard analysis includes data collection and analysis (seismological catalogs from various agencies, including historical reports; analysis with respect to: a. magnitude homogenization, b. focal depth, c. magnitude thresholds for completeness, d. declustering), identification of seismogenic zones and faults (active fault information and fault activity quantification; regional seismotectonic models), the generation of a zonation model and the selection of ground motion prediction equations in order to build a hazard model with recurrence parameters (zones of distinct activity and faults of distinct potentials; activity rates; magnitude – frequency scaling parameters; minimum and maximum magnitudes; definition of Poissonian versus characteristic earthquake recurrence). Hazard computations are conducted in a logic tree computational scheme for various spectral ordinates as well as return periods.

The outcomes of the hazard studies will serve as input for both deterministic and probabilistic damage and loss computations for selected test bed cities, i.e. Guwahati (Assam) and Thimphu

(Bhutan). Large efforts are spent on the collection of reliable building exposure information as well as the generation of vulnerability estimates for the prevalent building typologies in the region. Applying the analytical approach (FEMA, 2003) damage and loss estimates are predicted for the general building stock considering amplification effects of local soil conditions as well as surface topography.

In summary it should be stressed that the EQRisk project is unique with respect to the fact that both earth scientists and engineers from India, Bhutan and Norway are working together in a collaborative way.

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