Geodynamics and potentiality of large earthquakes in densely populated Bangladesh: Constrained from GPS

Syed Humayun Akhter[1,1] and Michael Steckler[2,2]

[1]Dhaka University
[2]Columbia University

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Abstract

Bangladesh, a small and over populated country in Southeast Asia occupies most of the Bengal Basin that results from sediments derived from the collision of India with Asia. The basin is filled with a 19 km thick sequence of Cenozoic sediments deposited by the mighty rivers Ganges and Brahmaputra. Unconsolidated Holocene sediments susceptible to seismic amplification characterize the upper part of the Cenozoic sequence. Bangladesh sits a top on three tectonic plates; India, Tibet and Burma. The India plate is colliding with the Tibet subplate to the north, which gives rise to great Himalayas, while to the east it is subducting beneath Burma and Sunda slivers, which gave rise to Indo-Burma arc. The Surma basin of NE Bangladesh is being underthrust under the Shillong massif producing the 2-km high plateau. The Indo-Burma fold and thrust belt results from the oblique subduction of the thick sediments of the Bengal Basin on the India plate that has deformed into a series of north-south trending en-echelon folds and thrust faults. The faults rooting these folds and the underlying megathrust are capable of generating devastating earthquakes in and around Bangladesh. Past earthquakes have brought changes to the landscape, avulsion of rivers Brahmaputra and Meghna, migration of human settlements, and widespread sand liquefactions and sand and/or mud eruptions. Our GPS study demonstrated that the landward extension of Andaman-Sumatra subduction zone into Indo-Burma subduction in deltaic Bangladesh is active. The present day India-Burma oblique convergence rate is 17 mm/y and that the décollement beneath the fold-thrust belt is locked (Steckler et. al., 2016). The western part of the subduction zone over a shallow décollement shows little seismicity whereas the eastern part shows moderate seismicity of magnitude 4 to 6. Based on the GPS velocity across the fold belt and seismicity the Indo-Burma subduction zone can be potentially be divided into locked western segment and slipping eastern segment, analogous to Cascadia subduction zone. Fold belt parallel shortening across Dauki Fault in Shillong is 7 mm/yr, which is another potential source of a large earthquake. The huge population might be severely ravaged by devastating earthquakes from both these sources.

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Syed Humayun Akhter[1], Michael S. Steckler[2]
[1]Department of Geology, University of Dhaka, Dhaka, Bangladesh, [2]Lamont-Doherty Earth Observatory, Columbia University, New York, USA

Email: 1. shakhter@du.ac.bd 2. steckler@ldeo.columbia.edu

Abstract

Bangladesh, a small and over populated country in Southeast Asia occupies most of the Bengal Basin that results from sediments derived from the collision of India with Asia. The basin is filled with a 19-20 km thick sequence of Mesozoic-Cenozoic sediments deposited by the mighty rivers Ganges and Brahmaputra. Unconsolidated Holocene sediments susceptible to seismic amplification characterize the upper part of the Cenozoic sequence. Bangladesh sits a top on three tectonic plates; India, Eurasia and Burma. The India plate is colliding with the Eurasia to the north, which gives rise to great Himalayas, while to the east it is obliquely subducting beneath the Burma and Sunda slivers, which gave rise to Indo-Burma arc. The Surma basin of NE Bangladesh is being underthrust under the Shillong massif producing the 2-km high plateau. The Indo-Burma fold and thrust belt results from the oblique subduction of the thick sediments of the Bengal Basin on the India plate that has deformed into a series of north-south trending en-echelon folds and thrust faults. The faults rooting these folds and the underlying megathrust are capable of generating devastating earthquakes in and around Bangladesh. Past earthquakes have brought changes to the landscape, avulsion of rivers Brahmaputra and Meghna, migration of human settlements, and widespread sand liquefactions and sand and/or mud eruptions.

Our GPS study demonstrated that the landward extension of Andaman-Sumatra subduction zone into Indo-Burma subduction in deltaic Bangladesh is active. The present day India-Burma oblique convergence rate is 17 mm/y and that the décollement beneath the fold-thrust belt is locked (Steckler et. al., 2016). The western part of the subduction zone over a shallow décollement shows little seismicity whereas the eastern part shows moderate seismicity of magnitude 4 to 6. Avulsions and sand dikes may record past earthquakes of magnitude 7-7.5 in the accretionary prism. The megathrust offshore Myanmar and SE Bangladesh ruptured in a megathrust earthquake is 1762. Fold belt parallel N-S shortening across Dauki Fault in Shillong is 7 mm/yr, decreasing westward, which is another potential source of a large earthquake. The huge population might be severely ravaged by devastating earthquakes from both these sources.

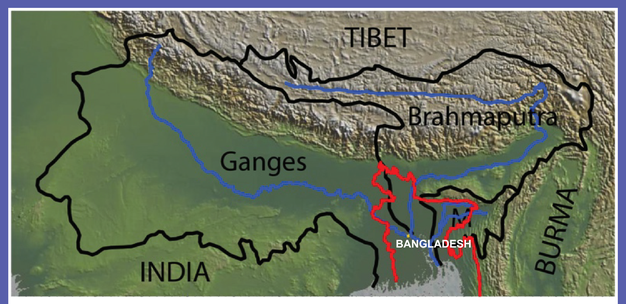


Figure 1: Bangladesh, a densely populated country in southeast Asia, is located in the northeastern part of Indian sub-continent at the head of Bay of Bengal. Tectonically, Bangladesh lies in the northeastern Indian plate near the edge of the Indian craton and at the junction of three tectonic plates – the India plate, the Eurasian plate and the Burma subplate. The collision of India with Eurasia about 50 million years ago gave rise to great Himalaya to the north and Indo-Burma Ranges to the east. These form two boundaries where plates converge– the India-Eurasia plate boundary to the north forming the Himalaya Arc and the India-Burma plate boundary to the east forming the IndoBurma Arc. The Indian plate is moving ~6 cm/yr in a northeast direction and colliding with the Eurasian (@ 45 mm/yr) and the Burmese (@ 46 mm/yr) plates in the north and east respectively. The plate motion with buildup of strain energy beneath the delta is a great risk of earthquake to populated Bangladesh.

Bangladesh occupies major part of the Bengal Basin and entirely sits on the Ganges-Brahmaputra-Meghna (GBM) Delta – which is the largest in the world. The Ganges and Brahmaputra Rivers drain 3/4of the Himalayas and supply over one billion tons of sediment to the delta each year. The delta is very active with rapid sedimentation and high subsidence rate. The GBM Delta formation and progradation records the interplay of sediment dynamics and convergent tectonics.

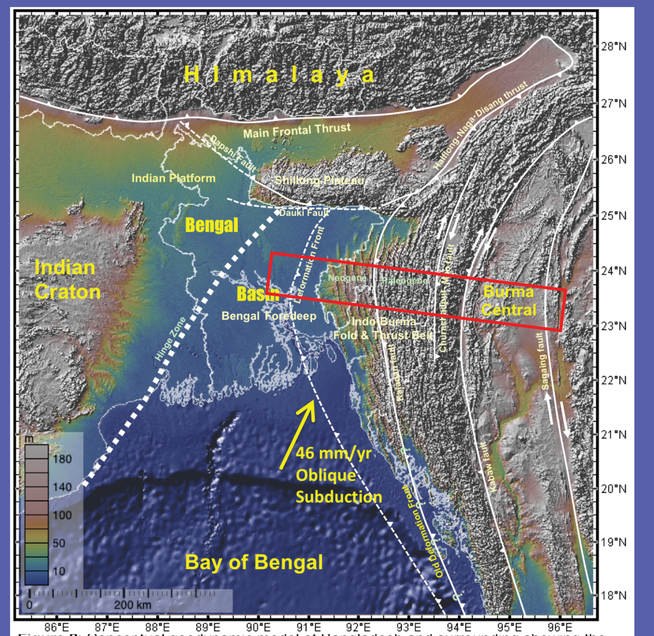


Figure 2: Conceptual geodynamic model of Bangladesh and surrounding showing the major tectonic elements. About 88% of the country is low-lying flat landscape with up to 19-20 km thick sequence of Cenozoic sediments. The rest 12% landmass in eastern Bangladesh and its continuation further to the east in northeast India and Myanmar represents Tertiary hills – known as Indo-Burma Ranges. The Tertiary hills are characterized by a 250 km wide and 1400 km long accretionary prism resulting from the oblique convergence of India-Burma plates. The acretionary prism is deformed into a series of N-S trending *en echelon* folds and thrust faults. It marks the subduction zone between the subducting Indian plate and overriding Burma plate - a landward northern extension of the Sumatra–Andaman subduction zone. The western most structures along the eastern shore are uplifted and form terraces from the 1762 megathrust earthquake. This fold and thrust belt evolved through a process of two generations of deformation- during Paleogene Myanmar-Mizoram segment came into being and secondly Chittagong-Tripura segment was uplifted during late Neogene when the Bengal Basin reached the subduction zone. The anticlines of Paleogene deformation are very close, tightly and intensely folded whereas the anticlines of Neogene deformation are widely separated by broad synclines. The Paleogene and Neogene structures are separated by Kaladan fault, and out-of-sequence fault. Topographically, these two deformation sytems show striking change in elevation. The deformation advances westward into the deltaic Bangladesh. The deformation front runs near the low elevation Meghna estuary to the south and Sunamgong-Kishorgong marshes to the north. The red box shows the location of the ongoing Tripartite geophysical transect (more posters Tues. morning)

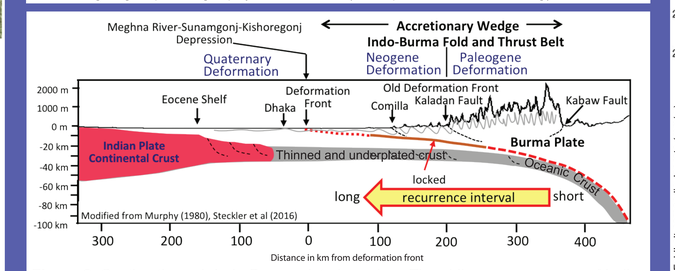


Figure 3: Section through Indo-Burma plate boundary. The oblique convergence of India plate with Burma plate produced ≈250 km wide accretionary wedge on the upper plate with folds and thrust faults. The Indo-Burma subduction in onshore Bangladesh is active with ~17 mm/yr plate convergence. About 19 km thick sediments over the Indian thinned continental to oceanic plate is gently folded and underthrusting to the Burma plate. The total shortening of the outer wedge is approximately 42 km. The Burma plate is locked beneath the accretionary wedge and its tip is blind under the alluvium plain in Bangladesh.

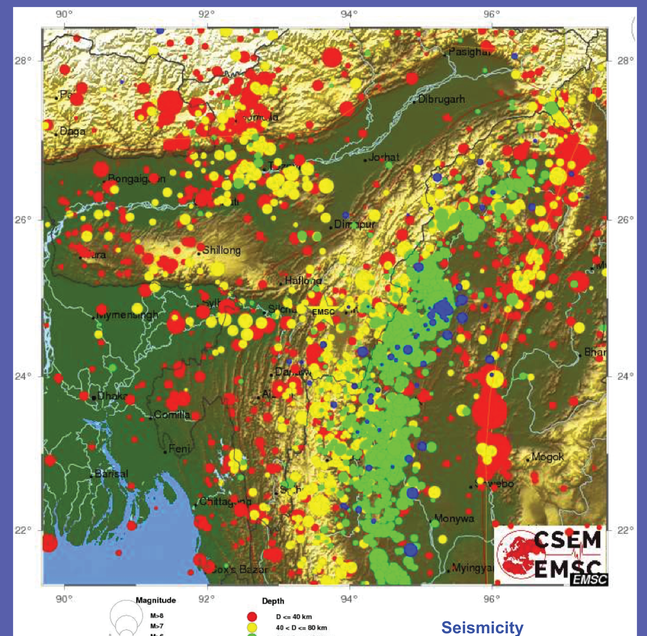
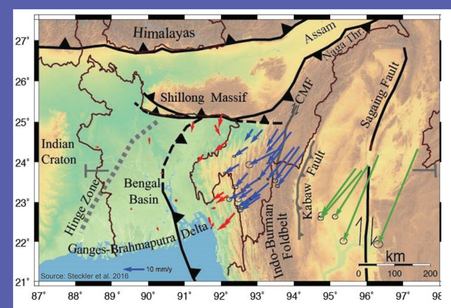


Figure 4: Seismicity map of Bangladesh and its neighborhood. Though Bangladesh sits at or near the juncture of three tectonic plates yet it demonstrates relatively low seismicity. In general, Bangladesh is a country of low seismicity. Much of the seismicity is located or confined in Indo-Burma subduction zone particularly in Paleogene deformation system of Myanmar-Mizoram belt. The Neogene deformation system of Chittagong-Tripura fold belt has little or no seismicity indicating a state of locked condition of the plates. Deep focus earthquakes illuminate the bending of subducting Indian slab.



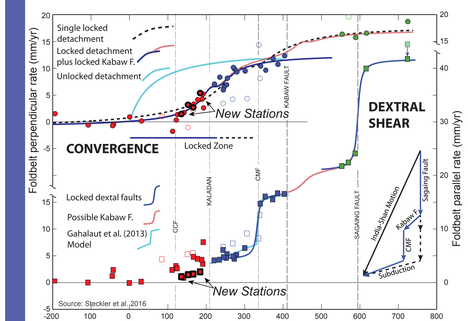


Figure 5: GPS velocities of our network processed with the data of campaign stations of Myanmar and published data of Indian sites with Indian reference frame fixed. Red colour vectors are from Bangladesh GPS network, blue colour vectors represent northeastern India GPS network and green colour vectors represent Myanmar GPS network. The convergence across the Indo-Burma fold and thrust belt is oblique and partioned. The velocity gradients across the wedge show E-W shortening of ~17 mm/yr and N-S dextral shear of ~41 mm/yr.

Bottom figure represents GPS velocity shortening across (circle) and shear parallel (square) to the fold belt. The velocity triangle shows the partitioning of the oblique motion between fold belt parallel and fold belt perpendicular.

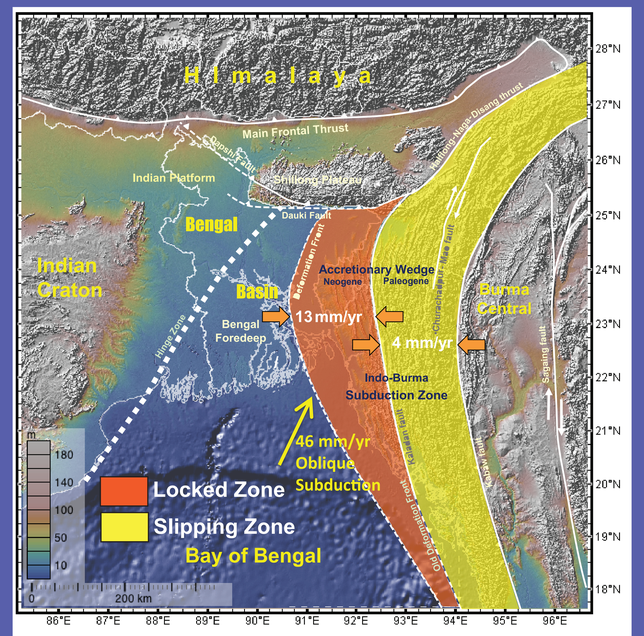
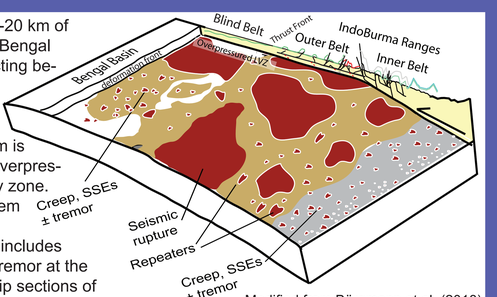


Figure 6: Our GPS velocity profile across the subduction zone demonstrates that the delta plain and the Chittagong-Myanmar fold belt has shortening rate of ~17 mm/yr which is partioned into 13 mm in the Chittagong-Tripura fold belt and 4 mm in Mizoram-Myanmar belt. Based on the seismicity pattern and variable GPS velocity the Chittagong-Tripura fold belt is locked and accumulating elastic strain. Most of the strike slip component of the oblique subduction is accomodated by the Sagaing Fault and multiple faults within the Mizoram-Myanmar belt. The distribution of faults accomodating the shortening is uncertain. Beneath the Mizoram-Myanmar segment the megathrust steepens into the subduction zone. We have calculated the amount of elastic strain that has been stored in the Chittagong-Tripura locked zone is capable to generate megathrust earthquake of Mw 8.2 to 9.0 magnitude. The capital city Dhaka is overlies the updip end of the locked zone. However, whether an earthquake would propogate to the deformation front in some earthquakes is unknown.

Figure 7: The 19-20 km of sediments of the Bengal Basin are subducting beneath the Indo-Burman Ranges. The >250 wide accretionary prism is underlain by an overpressured low velocity zone. Whether the system ruptures in large earthquakes and includes creep, SSE and tremor at the updip and downdip sections of the megathrust is unknown.



Modified from Bürgmann et al. (2018)
Section from Paul Betka, pers. comm.

Conclusion

The Indo-Burma subduction is characterized by shallowly dipping locked western zone. Whether there is periodic slow slip in the eastern zone, analogous to the Cascadia subduction zone is unknown. The potential for a great earthquake in Bangladesh, Northeast India and Myanmar has become a great threat to the large number of people of these regions. In-depth studies of the Indo-Burma convergence tectonics to better characterize the subduction zone with the Tripartite geophysical transect are underway.