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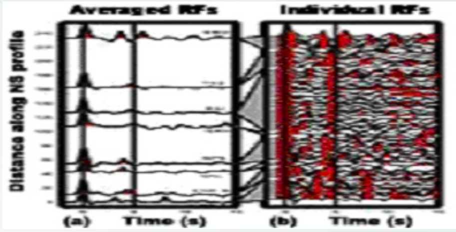
Solid Earth Modelling Programme (SEMP)

Highlights

- First ever Images and Rheology of the lower Crust of Northeastern India.

  Fine structure receiver functions representing converted shear wave phases at acoustic boundaries, obtained underneath a 700 km long south-north profile from Silchar on the Bengal basin using broadband seismic data.



- Estimation of the Convergence Rate and Crustal Structure Across the Northeastern Indo- Himalayan Collision Zone
- Discovery and Mapping of a Previously Unrecognized Active Regional Transverse Fault

Inside

- Establishment of 8 Continuous Recording Permanent GPS Sites in North-Eastern India
- Active Tectonics of the Shillong Plateau
- Active and Neotectonics of the Darjeeling-Sikkim Himalaya
- Influence of Source Distance on Site-Effects in Delhi
- Microzonation Investigations in Anzar (Kachchh) area using Microtremor Recordings
- Shear Wave Structure of the Crust Beneath North-Eastern India

2005 Perspectives

With the data from the GPS permanent and campaign stations regularly coming in, and building up on the computational and inverse modelling strength at C-MMACS, projected plan for the near future include: Modelling coherent site amplification of expected ground motion to create hazard potential map of selected urban areas over a 100m x 100m grid, and study of the undercarriage structure of other significant segments of the Indian continent using high-resolution acoustic images.

2.1 Establishment of 8 Continuous Recording Permanent GPS Sites in North-Eastern India

The Department of Science and Technology had requested C-MMACS to set up four permanent GPS stations in North-eastern India with the intention of initiating detailed GPS measurements to quantify and monitor the neotectonic activities in the region. In 2002, C-MMACS had installed five permanent GPS stations at Aizawl, Guwahati, Imphal, Lumami and Shillong. This activity was continued and brought to a close by the establishment of additional permanent stations at Bhopal, Pangthang (Gangtok) and Bomdilla. The Bhopal station was set up in collaboration with Regional Research Laboratory, Bhopal. The Pangthang station was set up in collaboration with G. B. Pant Institute of Himalayan Environment and Development, Gangtok and the Bomdilla station with Indian Institute of Astrophysics and Tezpur University. Consequently, we now have a total of 8 stations; Aizawl, Bomdilla, Guwahati, Imphal, Lumami, Panthang, Shillong and Tezpur permanent GPS running in NE India and the stage is set of more detailed investigations of active tectonics in the region.

Sridevi Jade, Malay Mukul, A P Krishna, M V R L Murthy and V K Gaur

2.2 Active Tectonics of the Shillong Plateau

The next phase of the Department of Science and Technology initiative in North East India to carry out detailed campaign mode GPS measurements has been jointly taken up by National Geophysical Research Institute, Hyderabad and C-MMACS in collaboration with local universities. C-MMACS, in collaboration with IMD, Shillong and Tezpur University have made two epochs of measurements in the Shillong Plateau between 2002-2003. These measurements seem to indicate that there was practically no active deformation within the plateau during 2002-2003. However, these measurements, when combined with the data from IGS station at Lhasa, seem to indicate that there is strong lateral variation in the convergence rates in the North East Himalayas from west to east. Here, averaged convergence rates range from 7.33±1.52 mm/year in Sikkim-Western Bhutan, to 16±3.5 mm/year in Eastern Bhutan, to 44±9 mm/year in Arunachal Himalayas. We will need to track these rates for several more years to ascertain whether these average rates are representative.

Malay Mukul, Sridevi Jade, Anjan Bhattacharyya, Rivertis Pariong and V K Gaur

2.3 Active and Neotectonics of the Darjeeling-Sikkim Himalaya

The Darjeeling-Sikkim Himalayan region has thrown up several scientific enigmas in our understanding of the kinematics of Himalayan deformation. First, although the geology seems to indicate signatures of thrust deformation, the region is dominated by strike-slip earthquakes. Second, in this region the surface traces of the Main Central Thrust and the Main Boundary Thrust come very close together. Third, the entire Siwalik sequence disappears abruptly for about 50 km and the mountain front recedes to the north by almost 10-15 km. These anomalies in the general style of deformation in the Himalayas have been investigated by C-MMACS in collaboration with Asutosh College and GBPIHED, Gangtok. We have cracked the first and the third puzzles and discovered and mapped a previously unrecognized active, regional transverse fault that is the source of the strike slip earthquakes and has behaved as a mechanical boundary. We have called this the Gish Transverse Fault and have mapped it to the Indo-Chinese border. The kinematics of deformation on the east and west side of the fault are entirely different and the recess in the mountain front is the result of this faulting. Detailed study of the deformation in the Gish transverse zone that involves the use of integrated tools such as field studies, remote sensing data, GPS Geodesy and quantitative strain measurements from thin-sections of rocks is currently underway under financial support from Department of Science and Technology.

Malay Mukul, Abdul Matin, Sridevi Jade and A P Krishna

2.4 Influence of Source Distance on Site-Effects in Delhi

Amplification of earthquake-induced seismic waves by soft superficial deposits often causes significant damage in urban areas. Significant research work during the last two decades concerns the problem of ground response estimation. Most of this research has been carried out a posteriori (i.e. after the occurrence of a destructive earthquake) using mainly experimental methods such as Standard Spectral Ratio (SSR), Horizontal to Vertical Spectral Ratio (HVSR), etc. Recently, several theoretical methods (such as finite difference, finite element or modal summation) have been employed in order to develop 1-D, 2-D or 3-D numerical techniques for a priori estimation of ground amplification. The main question that that arises is whether the response estimated at a specific site depends only on the local geological and geotechnical characteristics or on other factors as well. In the present study, we study the uniqueness of the so-called site effect by Examining the source-distance influence on the ground amplification variations.

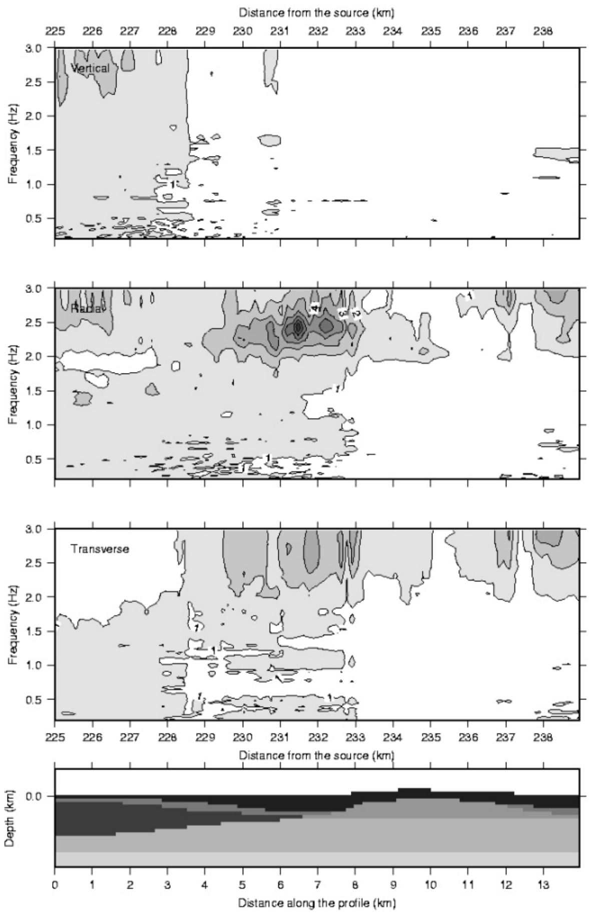


Fig 2.1 The cross-section and corresponding plot of response spectra ratio (RSR) versus frequency, when the source is far at a distance of 225 km.

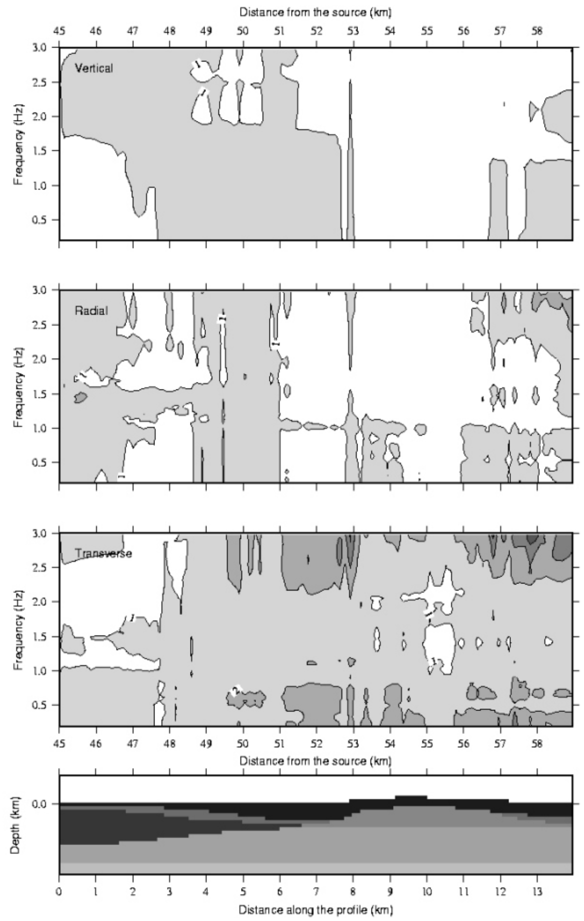


Fig 2.2 The cross-section and corresponding plot of response spectra ratio (RSR) versus frequency, when the source is near at a distance of 45 km.

We simulate the seismic ground motion along a geological cross-section from Tilak Bridge to Punjabi Bagh in Delhi city at every 130 meters with a hybrid technique (modal summation and finite differences). The hybrid method employed for the computation of the ground response along the various profiles combines the modal summation and the finite difference methods. The former one allows us to generate the wavefield and to take into account the path from the source position to the boundary of the target area, while the latter permits the modeling of wave propagation in complicated and rapidly varying velocity structures within the target area, as is required when dealing with sedimentary basins. We use two earthquake source scenarios: (1) August 27, 1960, M=6.0 at a distance of about 45 km (near source) and (2) a large (M=8.0) earthquake due in the central seismic gap in the Himalayan region, at a distance of about 225 km (far source). The response spectra ratio (RSR), ie the response spectra computed from the signals synthesized along the laterally varying section normalized by the response spectra computed from the corresponding signals, synthesized for the bedrock reference regional model, have been determined. The aim of the present study is to see the influence of source distance on the site-effects along the same profile. We compare the Response Spectra Ratio (RSR) for frequency up to 3 Hz, computed due to far and near sources. We observe 4-5 times high amplification in the radial component at around 2-2.5 Hz due to the far source (Fig 2.1), as compared to the near source (Fig 2.2). However, there is some amplification, of the order 2-3, at lower frequencies (less than 1 Hz) due to the near source, which is missing when considering the far source. We focus on the influence of the seismic source location on site-response, which, in general, is neglected in traditional site-effect studies. To validate our results, we compare the RSR, obtained from the signals at soft sites, namely CPCB, IHC and CSIR, normalized to the bedrock Ridge site, recorded during Chamoli earthquake of 1999, with the RSR at similar sites theoretically computed along our 2-D geological cross-sections. Our results compare well and are in good agreement with the observed data set.

Imtiyaz A Parvez, F Vaccari and G F Panza

2.5 Preliminary results on Microzonation Investigations in Anzar (Kachchh) area using microtremor recordings.

A devastating earthquake of magnitude Mw 7.7 rocked the Kachchh District of Gujarat on January 26, 2001. This earthquake was the most deadly in India's recorded history in the sense of causalities and destruction. The earthquake epicentre was located northwest of Bhachau but the shock was felt by almost the whole Indian subcontinent. The places in the epicentral zone were completely damaged irrespective of the ground condition, however, other major populated towns like Bhuj, Anzar, Gandhidham etc. observed comparatively less but contrasting damage scenarios.

The Department of Science and Technology (DST), Government of India has sponsored an Indo-French project to C-MMACS for conducting microtremor observation in Anzar town to study the site response and building parameters, where drastic differences were observed in the damage distribution. The aim of the project is to record microtremor ambient noise and have an estimate of the soil fundamental frequency distribution using the H/V ratio technique. The first preliminary field work in the region is conducted during Feb/March, 2004 and we occupied nearly 70 stations to record ambient noise within the old part of Anzar town as well as surrounding peripheral. We used two CityShark stations and two 5-seconds Lennartz seismometers for the field work. The instruments were brought by our French counter-parts and field expenses and logistic support were provided by C-MMACS through the DST grant. Detailed field work with more regular and dense location will be carried out in the next visit by the end of this year.

Fig 2.3 shows the map of Anzar town and the places used to conduct the microtremor recordings. The centre of the City is called the Gamtal area and suffered the maximum damage during the earthquakes. As per the local villagers, some of the houses sank by about a storey. The damage in the 1956 earthquake was also very high in this part of the town, whereas the houses in the north and north-west of Gamtal were relatively less damaged. We began our measurements along the EW profile of Gamtal and then we occupied several other points surrounding Gamtal area. Fig 2.4 shows the H/V spectral ratio obtained from the microtremor recordings in mostly Gamtal area. It generally shows the peak amplification, while couple of figures show the hard soil type characteristics. In general, we see two peaks in all the figures, one is around 10 Hz and other around 0.3-0.5 Hz. The former peak suggests the thin surface layer and latter implies the complex deep ground structure. Fig 2.5 compiles the example of H/V ratio obtained in undamaged or low damaged area, where generally we see flat response, without any peak amplification. In this case also, a peak around 10 Hz is common in all cases.

This is a preliminary study, just to get an idea of site response in different parts of Anzar town. However,

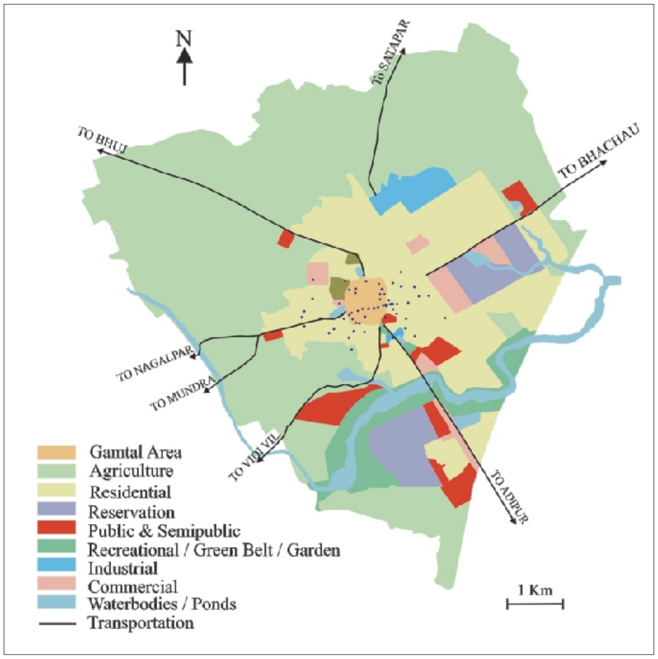


Fig 2.3 The city development plan for Anzar (Simtal) area. The points show the places where microtremor recorded.

a detailed field work within 100-200 meters of spacing along the whole town will be carried out by the end of this year. Final conclusions can be drawn only after mapping the site response along the whole region. It is also important to mention here that if this project had begun immediately after the

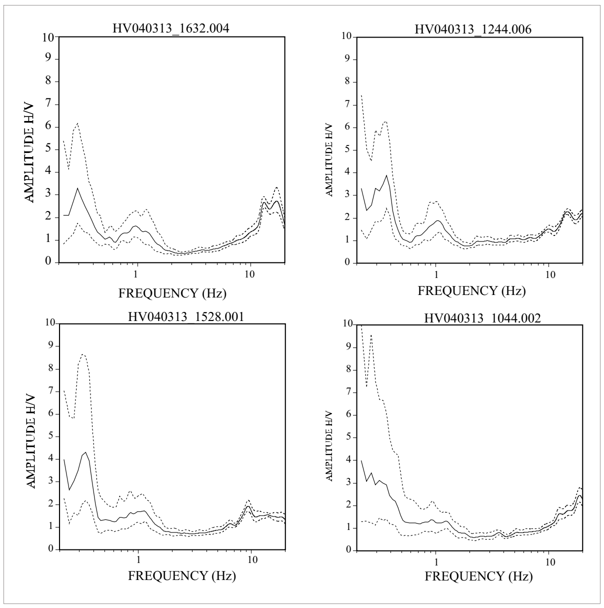


Fig 2.4 The plots of H/V spectra ratios versus frequency in damaged (Gamtal) area of Anzar.

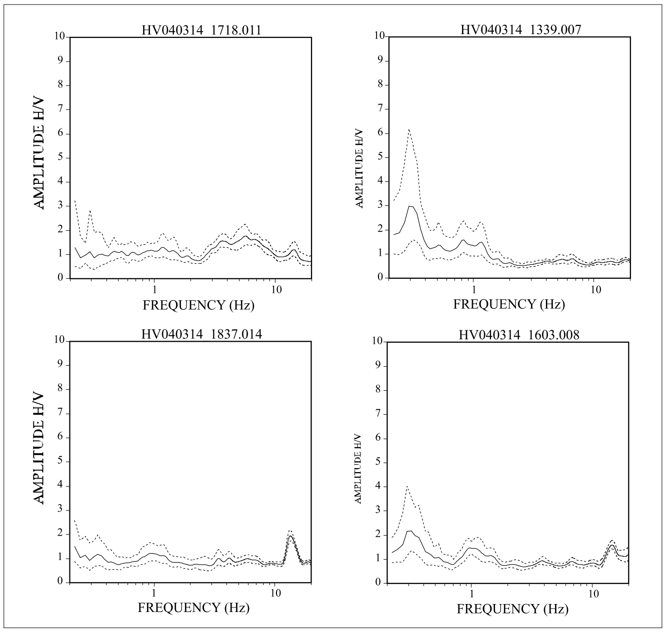


Fig 2.5 The plots of H/V spectra ratios versus frequency in undamaged or relatively less damaged area surrounding Gamtal.

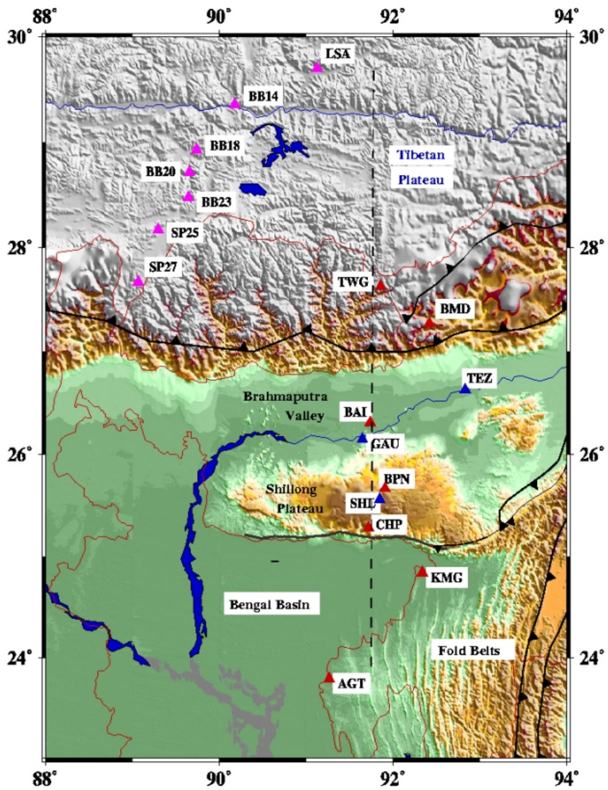
earthquake, the damage pattern would have been seen by our team. Due to a delay of almost three years, mixed opinion about the damage was reported by different people and different agencies. Many houses were manually demolished under the Anzar city development plan and yield wrong impressions of damage by the earthquake.

*Imtiyaz A Parvez, Jean-Luc Chatelain and Bertrand Guillier**

2.6 Shear wave structure of the crust beneath North-Eastern India.

The main objective of this study was to determine the elastic structure of the NE Indian collision zone, comprising the Bengal Basin, Shillong Plateau, the Brahmaputra Valley and the eastern Himalayas and the southern Tibetan Plateau, to illuminate the deformation of the Indian lithosphere across the collision zone. An experiment was accordingly designed to address three issues: (i) the processes that support the uncompensated elevation of the Shillong Plateau, (ii) the Moho geometry of the Indian crust as it underthrusts the eastern Himalaya and southern Tibet, and (iii) the depth of seismicity beneath the region as indicative of strength. To accomplish the above goals, broadband seismic data (Fig 2.6) recorded at six stations, from Agartala (23.78°N, 91.27°E) in the Bengal Basin to Tawang

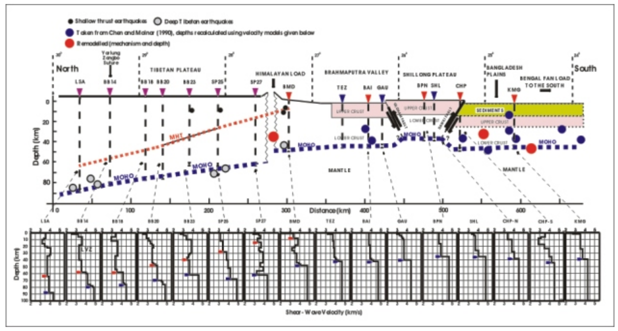
(27.62°N, 91.85°E) in eastern Himalaya, were analyzed. The seismic images thus obtained of the crust beneath the region traversing the Shillong Plateau and the Brahmaputra Valley were extended further northward by analyzing



INDEPTH II stations in southern Tibet, immediately to the north of our profile. Teleseismic Receiver functions calculated

Fig 2.6 Physiographic map of North-east India collision zone sandwiched between two mountain system, showing the main tectonic units of the region. Filled circles denote sites of seismic recordings, whilst the triangle mark the INDEPTH II sites for which available data were inverted. The North-south vertical line denotes the profile onto which the crustal sections and earthquake focal depths are projected.

from these data (Fig. 2.7) show that the crust is thinnest (~35-38 km) beneath the Shillong Plateau. Receiver functions at Cherrapunji, on the southern edge of the Shillong Plateau have a strong azimuthal dependance. Events from northern backazimuth show that the Moho beneath the southernmost Shillong Plateau is at ~38 km depth while receiver functions from southern backazimuth events show that the Moho beneath the northernmost Bengal Basin is depressed by 6 km to ~44 km depth. Receiver functions from sites on the Brahmaputra Valley



show that the Moho is deeper by ~7 km than below the Shillong Plateau (Fig. 2.7). This result agrees

Fig 2.7 The figure shows a schematic N-S profile of the crustal model inverted from Receiver Functions from Southern Tibet to Bengal basin. The Moho-rovicic discontinuity and the Main Himalayan Thrust are labeled MOHO and MHT and marked by vertical dashed lines with error bars. Earthquakes located ~300 km either side of the profile have been projected on the N-S profiles to show their depth locations in relation to the crustal section, thereby illustrating the rheology of the crust and the upper mantle in the region. The source of the hypocentral parameters of these earthquakes is indicated at upper left.

with the hypothesis (Bilham and England, 2001) that the Shillong Plateau is supported by shearing on two steep faults that cut through the crust and possibly through the upper mantle . Further north of the eastern Himalayan foredeep, the Moho dips gently northwards reaching a depth of ~48 km beneath Bomdila in the Lesser Himalaya, and 88 km below Lhasa in Tibet. Using the crustal velocity models obtained from receiver function inversions, we re-determined focal depths of well recorded earthquakes across this part of the Indo-Tibetan collision zone and all these are found to occur within the crust, indicating that no significant mantle seismicity exists beneath this region of NE India (Fig. 2.7), and that the lower crust in the region is strong enough to sustain faulting.

V K Gaur and S Mitra