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सत्यमेव जयते

nidm
Towards a disaster free India

National Workshop on

Earthquake Risk Mitigation
Strategy in North East

February 24-25, 2011, Guwahati, Assam

NATIONAL WORKSHOP ON

EARTHQUAKE RISK MITIGATION STRATEGY IN THE NORTH EAST REGION

Guwahati, Assam

24-25 February 2011

BACKGROUND PAPERS

Edited by

P.G.Dhar Chakrabarti

Chandan Ghosh

National Institute of Disaster Management

New Delhi

Contents

Preface

Based on the geotectonic features, history of past seismic events and potential hazards from earthquakes, the entire northeastern region of India has been included in the severe seismic Zone V of BIS code. At least a dozen mega earthquakes of more than 7 in the Richter scale had devastated the region during the past eleven and half decades and at least two of them - the great Shillong earthquake of 1897 and the Assam earthquake of 1950, both recorded 8.7 in the Richter scale, are considered among the most severe earthquakes anywhere in the world. Scientists have been warning of the recurrence of such extreme events anytime now as the 'return periods' of such mega shakes are stated to have become long overdue.

Dr. Roger Bilham of the University of Colorado, one of the most respected seismologists, had this to say to warn the policy makers in 2006:

> ***"Our findings show that great earthquakes - those with a magnitude of 8.2 or greater - can re-rupture Himalayan regions that already have ruptured in recent smaller earthquakes, or those with a magnitude of 7.8 or below. The current conditions might trigger at least four earthquakes greater than 8.0 magnitude, but if they delay, the strain accumulated during the centuries provokes more catastrophic mega earthquakes".***

Dr. Harsh Gupta, former Director of National Geophysical Research Institute, Hyderabad and another globally acclaimed geophysicist was more specific in his prediction in 1986, which in fact was vindicated by the 7.5 earthquake in Indo-Myanmar border on 6 August 1988.

> ***"Moderate magnitude to great earthquakes in the northeast India region is found to be preceded, generally, by well defined earthquake swarms and quiescence periods. On the basis of earthquake swarm and quiescence period, an area bound by 21 deg N and 25 ½ deg N latitude and 93 deg E and 96 deg E longitude is identified to be the site of a possible future earthquake of M 8 + 1- ½ with a focal depth of 100 +/- 40 km. This earthquake should occur any time from now onwards."***

If the policy makers and administrators at the national, state and local levels ignore such specific advisories from the most credible sources and fail to take necessary measures for mitigation and preparedness for such catastrophic events, the blame would lie squarely on them.

In order to sensitize the policy makers of the North Eastern region about the natural ‘time bomb’ on which the geology, geomorphology and geography of the region are embedded, the National Institute of Disaster Management, in collaboration with the National Disaster Management Authority, the North Eastern Council and the Government of Assam have organized a National Workshop on Earthquake Risk Mitigation Strategy in Guwahati on 24-25 February 2011. This workshop would bring together some of the most reputed experts who have devoted their life and career in understanding the hazards of earthquakes in the region to interact with the policy makers, jointly identify the strategic issues and develop a road map for earthquake risk mitigation and preparedness for the region.

This publication introduces some of the scientific, historical, social, economic and developmental issues that should inform and guide the deliberations in the workshop.

P.G.Dhar Chakrabarti
Executive Director
National Institute of Disaster Management

MESSAGES

सत्यमेव जयते

राष्ट्रपति
भारत गणतंत्र
PRESIDENT
REPUBLIC OF INDIA

MESSAGE

I am happy to learn that the National Institute of Disaster Management in collaboration with the National disaster Management Authority, North Eastern Council and the Government of Assam is organizing a National Workshop on Earthquake risk Mitigation Strategy on February 24-25, 2011 at Guwahati.

The workshop could be an occasion for professionals from disciplines such as engineering, architecture, science and planning to discuss practical ways to mitigate natural disaster. Delegates can also share their experiences on risk mitigation.

On this occasion, I extend my warm greetings and felicitations to the organizers and the participants and wish the Workshop every success.

Pratibha Patil

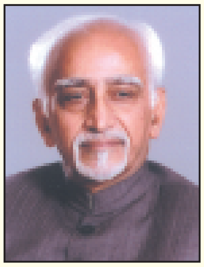
(Pratibha Devisingh Patil)

New Delhi
February 11, 2011

सत्यमेव जयते

उप-राष्ट्रपति, भारत

VICE- PRESIDENT OF INDIA



MESSAGE

I am glad to know that the National Institute of Disaster Management (NIDM) is organizing a National Workshop on 'Earthquake Risk Mitigation Strategy' on February 24-25, 2011 at Guwahati.

Within a short period the NIDM has emerged as one of our key institution in the field of disaster management. The NIDM also encourages inter-disciplinary research on disaster management to enhance regional cooperation.

I extend my greetings and good wishes to all those associated with the NIDM and wish the workshop all success

(M. HAMID ANSARI)

New Delhi
9th February, 2011

सत्यमेव जयते

गृह मंत्री
भारत
नई दिल्ली -110001

HOME MINISTER
INDIA
NEW DELHI - 110001

February 19, 2011

MESSAGE

I am happy to learn that National Institute of Disaster Management, in collaboration with the National Disaster Management Authority, the North Eastern Council and the Government of Assam is organizing a National Workshop on "Earthquake Risk Mitigation Strategy in the North East" in Guwahati on 24-25 February 2011. This is a welcome initiative as this region has witnessed several earthquakes and the seismologists have been warning of the recurrence of such earthquakes in future. It is expected that this workshop would bring together reputed experts on earthquake in the region to interact with policy makers and administrators and develop a road map for earthquake risk mitigation and preparedness for the region.

I look forward to the concrete recommendations of the workshop which would help the Government to take mitigation initiatives to save the people from any such future disaster. I wish the workshop all success.

(P. Chidambaram)

DORJEE KHANDU
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MESSAGE

I am extremely delighted to learn that the National Institute of Disaster Management, Ministry of Home Affairs in collaboration with National Disaster Management Authority, North Eastern Council and Government of Assam is organizing a two day National Workshop on "Earthquake Risk Mitigation Strategy in the North East" at Guwahati on February 24-25, 2011.

Since, the Entire North East fall in the Seismic Zone V making it very vulnerable to disaster especially from Earth Quakes, there is an urgent need to chalk out plan and preparedness to mitigate the earthquake disaster.

The very thought of publishing a Souvenir on such occasion carrying interesting scientific articles, research work of our learned scientists is a significant approach. I hope, it will be informative and would prove to be a valued archive in the years to come.

I on behalf of my cabinet colleagues and of course on my own behalf express my best wishes for the National Workshop on "Earthquake Risk Mitigation Strategy in the North East".

(Dorjee Khandu)

Tarun Gogoi

Chief Minister, Assam
Guwahati

Dispur
11th February, 2011

MESSAGE

I am happy to know that National Institute of Disaster Management is organizing a two-day National Workshop on Earthquake Risk Mitigation Strategy in the North East at Guwahati on 24th and 25th February, 2011 and a souvenir is being published on the occasion.

Assam and the North East region fall in the high seismic zone V. Several earthquakes of great intensity rocked the region in the past which have had resulted in loss of human lives and properties. As scientists have been warning of earthquakes striking again in the region, it calls for evolving of concrete strategies on risk mitigation. I hope the deliberations in the workshop will go a long way in our preparedness to face the challenges that may confront us in the event of any exigency.

I wish the national workshop all success.

(TARUN GOGOI)

CHIEF MINISTER
MANIPUR

Imphal
February 17, 2011

MESSAGE

It gives me immense pleasure to learn that the National Institute of Disaster Management in collaboration with National Disaster Management Authority, North Eastern Council and Government of Assam is organizing a two-day National Workshop on Earthquake Risk Mitigation Strategy in the North East on 24th and 25th February, 2011 at Guwahati, Assam.

Earthquakes are one of the worst among the natural disasters. These have caused a heavy toll in terms of the loss of human lives, property and livelihood. Management of disasters requires skills and capabilities to effectively deal with the whole cycle of disaster management. There is a need for professionals who can play a pro-active role in disaster management. I am confident that the discussions, deliberations and interaction of the senior policy makers, subject matter specialists and experts from the region during the Workshop will go a long way towards developing further policies, plans and programs for reducing the risk of earthquakes in the North East region.

I extend my warm greetings and felicitations to all those who are associated with the Institute and wish the Workshop a grant success.

(O. Ibobi Singh)

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MESSAGE

It gives me immense pleasure to learn that the National Institute of Disaster Management in collaboration with National Disaster Management Authority, North Eastern Council and the Government of Assam is organizing a two-day National Workshop on Earthquake Risk Mitigation Strategy in the North East at Guwahati on 24th and 25th February, 2011.

One of the significant challenges faced by North Eastern Region of India is to improve their resilience against disaster particularly earthquake. Therefore, it is the emegent need of the hour to plan, discuss and implement schemes for mitigation of risks in this Region.

I sincerely hope the Workshop will develop a road map on earthquake risk mitigation for the North East Region.

I extend my heartiest greetings to the oganizers and participants and wish the Workshop a great success.

(LAL THANHAWLA)

Dated Aizawl
the 17th February, 2011.

CHIEF MINISTER
NAGALAND
KOHIMA

7th February, 2011

MESSAGE

I am happy to learn that the National Institute of Disaster Management, Ministry of Home Affairs, Government of India is is organizing a two days workshop on Earthquake Risk Mitigation Strategy in the North East. Earthquakes in its wake bring about misery, destruction to lives and properties. The workshop being organized to developed strategies for preparedness is the need of the hour; since the entire North East Region come under zone of extreme vulnerability to earthquakes.

I hope the workshop will enable the subject matter experts, policy makers to frame a cohesive and comprehensive strategy to benefit the North East Region

I wish the workshop a grand success

(NEIPHIU RIO)

Vice Chairman
National Disaster Management Authority
Government of India

MESSAGE

The entire North Eastern Region of India falls under the most high risk seismic zone V of our country. Catastrophic earthquakes measuring 8 plus in the Richter scale had devastated the region in the past and there are strong probabilities that such disasters may recur again. Growth of population and unsafe building practices have made the region extremely vulnerable to earthquakes.

In this context I welcome the initiative of the National Institute of Disaster Management to organize the National Workshop on Earthquake Risk Mitigation in collaboration with the National Disaster Management Authority, the North Eastern Council and the Government of Assam in Guwahati on 24-25 February 2011.

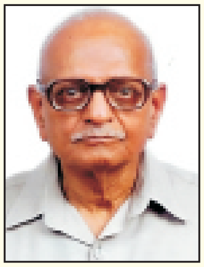
The National Disaster Management Authority has issued comprehensive guidelines on the management of earthquakes in the country. The guidelines have recommended six pillars for earthquake risk management in India, namely, earthquake resistant construction of new structures, selective seismic strengthening and retrofitting of existing priority and lifeline structures, regulation and enforcement, awareness and preparedness, capacity development and emergency response. The workshop should deliberate on the concrete measures that need to be taken for strengthening these pillars in the North Eastern Region.

I would be looking forward to see the recommendations of the workshop. I wish the workshop all success.

(M. SHASHIDHAR REDDY)

P. P. Shrivastav
Member, NEC

North Eastern Council
Shillong - 793 001



18th February, 2011

MESSAGE

I congratulate the NIDM for organising the National Conference on Earthquake Risk Management Strategy in the North East at Guwahati on the 24th and 25th of February. This is a most welcome initiative since as we all know, the North Eastern Region (NER) of our country falls in the high-intensity active Alpide-Himalayan seismic belt and is one of the six most earthquake prone areas of the World. Having suffered two great earthquakes, one in 1897 which was terrible enough and the other in 1950 which is reckoned as one of the world's worst earthquake disasters, we sincerely appreciate any step that strengthens our coping capability.

The paradigm shift from the old Post-Disaster Relief and Rehabilitation mindset to Pre-Disaster Preparedness and Risk-Reduction mandate of the Disaster Management Act, 2005, is a healthy development. The planning and implementing machinery is already in position in form of NDMA, SDMAs and the District DMAs. Enough knowledge and capability exists and there is no reason to delay implementation of risk-reduction measures in an effective manner. The sharp contrast between the lives lost in two recent (2010) comparable earthquakes, one in Haiti and and the other in Chile, has vividly highlighted the heavy cost of delay in preparedness in terms of heavy loss of invaluable lives and valuable property. The lesson should not be lost upon us.

In the above context, we greatly appreciate this initiative of NIDM. We are with the NIDM in this Conference and in all such initiatives in NER in the future. I am confident that the deliberations will lead to better inter-State coordination and meshing of State DM Plans with each other, since in NER the natural constraints are such that individual States may find it necessary to draw upon the resources of others in handling major disasters. The deliberations of the Conference will certainly enhance our collective capability to save more lives, property and public assets from earthquakes and earthquake triggered disasters.

I wish the Conference a great success.

(P P Shrivastav)

PAPERS

Assam Earthquake of 1950: Address to the Nation

Jawaharlal Nehru

In the aftermath of the Great Assam Earthquake of 15 August 1950, the Honorable Prime Minister of India, Jawaharlal Nehru visited Assam during 4-7 September 1950. On 9th of September 1950, the following was broadcast to the nation over All India Radio, New Delhi

Friends and Comrades,

I am going to speak to you tonight about Assam, where recently a great earthquake brought death and disaster too many, and to some extent changed even the outward features of the land. I have visited this border province of ours on several occasions in the past, when I was more carefree and had some leisure to float about on the broad bosom of that noble river, the Brahmaputra. Now, I went there summoned by the earthquake on a less peasant errand. Look at the map of India. You will find Assam on the northeastern corner bordering Tibet and China and Burma and Pakistan. Thus, from international point of view, this province of ours has a very special significance. In the old days also it was a frontier province, but the North East frontier was not considered particularly important and all our attention was concentrated on the North West frontier. Now, changing conditions have made this northern-east corner vital to us in many respects and I have no doubt that its importance will grow. From being a neglected outpost of an empire, it has become the meeting place of many nations and it might become in the future a highway between some of those countries and ours.

Within the borders of Assam and adjuring it are large tribal tracts, where many tribes in various stages of development have lived for ages past. Do not imagine that all these tribes are backward. Some of them are certainly backward in many ways, but others have developed their own peculiar institutions, often of a democratic nature, and are in some ways fairly advanced. All of them are very attractive, or so I have found them.

Ever since I first visited Assam many years ago, I have been attracted by the beautiful valley of the Brahmaputra and the mountains and forests that lie beyond. The people there have their own distinctive features. They are simple, unsophisticated and likeable. There is a very unusual combination of semi- tropical scenery and snow capped mountains. The Brahmaputra, after a long journey through Tibet, rushes down through mighty gorges into the Assam valley where it becomes a placid river, sometimes spreading out almost like a sea. Perhaps many of you think of Assam in connection with tea. These tea gardens, well tended and attractive looking, cover a large part of Assam. Apart from this, the chief cultivation of the State is paddy. Orange trees and pineapples and bamboos and palms and the beautiful and graceful areca tree, from which our supari comes, abound in the State.

In this peaceful State rather slow moving, came the sudden shock of the earthquake. It was the evening of August 15, when all over India some kind of celebrations had been organized for the Independence Day. Soon after half past seven, the earth trembled and shock and heaved up or subsided and houses tumbled down and great landslides occurred in the hills. Frightened people rushed about in the dark, not knowing what the fate of their neighbours might be. It took some time for people to get information of what had happened, because telegraph and telephone wires broke and other normal means of communication were disrupted. Slowly news trickled through and we realize the full extent of what has happened because several parts were completely cut off and it has not yet been possible to reach them.

It is said that the epicenter of the earthquake was somewhere in Tibet, near a place called Rima, some miles from the Assam frontier. We know nothing of what has happened in Tibet or on the mountainous regions of the border. As a result of the landslides, rivers were blocked up for a while, and then broke through, they came down with rush and a roar, a high wall of water sweeping down and flooding large areas and washing away villages and fields and gardens. These rivers have changed their colour and carried some sulphurous and other material which spread a horrible smell for some distance around them. The fish in them died. The remains of villages, animals, including cattle and elephants and large quantities of timber floated down these raging waters. Paddy fields were destroyed, stocks of grains were washed away and some tea gardens also suffered great damage.

It is difficult to estimate the damage that has been done. The loss of human life was not so great as it might have been in a more populous area. Probably not more than a thousand people have perished. Most of them died by being crushed by the landslides or swept away by the rivers in sudden flood. Some may have died or may be dying for lack of food. There are large areas still, more especially in the North Lakhimpur district, east of river Subansiri, which are very difficult of access and are water-logged. Even when one crosses this angry river Subansiri, and that is a difficult task, one has to face a combination of flood and forest, and internal movement not easy. There are numbers of people marooned in different parts of this area in North Lakhimpur. Beside this area there are the hills which are even more inaccessible and about which we have practically no information yet. There is no doubt, however, that the tribal people who live there have suffered and are suffering greatly.

The damage to public buildings and public works has been very heavy. National highways have been torn and twisted and have sometimes a strange, vertically wavy appearance. Bridges have been washed away or broken; railway lines have snapped or are twisted. Some of these roads and tracts will have to be realigned completely for long distances.

When the earthquake came, three parties, consisting of the Assam Rifles and some of our army men, were on their way to our frontier outpost. One such party, comprising twenty-five men of the Assam Rifles and sixty porters, was suddenly buried in the heavy landslides. They managed to escape, however, through rolling down the rocks except for four porters who lost their lives. But they lost everything they had- food, clothing, utensils, arms and ammunition, wireless set etc. They were marooned for a number of days without food. Ultimately a rescue party reached them. The second and third party also had strange and exiting experiences and had to be rescued right on the borders of Tibet. Some of them in fact could not come back at all, because the bridge over the river had been washed away and the only way for them was into Tibet. In the same way some Tibetans were cut off and marooned on the Indian side of the border and could not go back.

These are the difficulties which we have had to face. The Government of India naturally wanted to give the utmost help. The Air Force sent a number of Dakotas for dropping food in those areas which were cut off. Everyday our aircraft fly often through bad weather, taking rice and other foodstuff, and drop them for these starving people. We have now sent some smaller planes also for reconnaissance work as well as to land some of our officers in these marooned areas, if that is possible. In addition to our own aircraft, two small planes belonging to the tea companies have also done excellent work in carrying and dropping food in these areas. Then there is our army, which is rapidly trying to build up new roads and bridges and give such other help as they can. They are now organizing small parties of stout hearted men and strong swimmers who will brave the raging torrents and enter into that difficult region which has been cut off from us since the earthquake. Our railwaymen and engineers are working hard to get the railway function again. The restoration of communications is of the first importance.

Meanwhile, the Brahmaputra, spreading as far as eye can reach, flows along in an angry mood. It has changed its course at places and, at Dibrugarh, is cutting away into parts of the inhabited city. Some buildings and roads have already been smashed and consumed by its swirling waters. Our engineers are hard at work to stop this continuous erosion. Not much can be done at present. Later, more permanent methods will have to be employed.

Volunteer relief societies, local as well as from outside, are doing good work. I should specially like to mention the fine work being done by the staff and students of the Medical College at Dibrugarh. Here, in Assam, is a chance for every able-bodied man and woman of the State to help in relief and reconstruction. And so, while I know that Assam badly needs every kind of help from other parts of India, I called upon the people there to rely on themselves and to help each other and their province at this time of crisis.

I have told you briefly of conditions in Assam now. How can we help, as help we must, to the utmost of our capacity? It will do no good for large numbers of people to rush to Assam, for they will only become a burden there. Selected persons with special knowledge or capacity might be able to help. We can all help by subscribing generously to the Governor's relief fund. I shall gladly accept and forward any subscriptions that are sent to me. That is the least we can do. We can also help by strictly conserving the nation's food supply and preventing all waste and misuse. Every State Government must enforce its procurement schemes so that all available food can be utilized to the best advantage, not only in Assam but in other areas of scarcity. Even in Assam, while there is scarcity and famine and starvation in some areas, most of which are cut off from us for the present, there are other areas which are surplus. Effective procurement schemes must function there immediately as elsewhere.

Those who desire to profit by this emergency and hoard food grains or try to sell them at high prices in the black market must be considered enemies of society and should be dealt with as such. There can be no greater crime than for a person to make a profit at the cost of death to his fellow men. There has been often enough a certain timidity in this matter and the law with its interminable delays and complications frighten people. But the law is good enough and is meant to prevent evil and help in good deeds. It is men of strength that we need to enforce the law without fear or favour.

Disaster has descended upon many parts of our country. Assam has suffered most, but other States have had great floods and great losses. The only way to meet this is with a stern determination not to allow either nature's vagaries or men's follies to come in the way of the work we have to do.

On such occasions one inevitably thinks of the precarious hold that life has. A slight tremor of the earth's surface, a faint ripple, causes mountains to tumble, rivers to change their courses, and houses to collapse, and men to die. Whether it is long or short, life has the same inevitable end, but while it lasts, we can make it worthwhile or futile, noble or petty and mean. It is not by submission to evil or surrender even to nature's challenge or a mere passive looking on at what happens or empty prayer that life can be made worthwhile. The challenge has come to us in many ways in this country. It is up to us to answer that challenge in every department of life and public affairs with faith and confidence in ourselves and in our country.

Jai Hind.

Great Earthquake Occurrences of the North East

NIDM Research Team
National Institute of Disaster Mangemment, New Delhi

Administrative Staff College, Guwahati, Assam

Wedged between the collision boundaries of the Himalayan plate in the north and the Indo-Burmese plate in the east, the North Eastern region of India, comprising of the States of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura is one of the seismically most active regions of the world. With complex tectonic and geological set up of the region and intense continental convergence of the northward moving of Indian plate at the rate of 20+03mm/year mega earthquakes of magnitudes 8 and above have occurred in the past and are bound to occur again, although given the state of our knowledge it may be difficult to predict when, where and how. Historical records are replete with references of catastrophic earthquakes that caused large scale damage to lives and properties in the region, but in the absence of instrumentation the magnitude of these earthquakes cannot be authenticated. A huge earthquake is stated to have occurred during the reign of king Suklenfa of Ahom kingdom in 1548. The successive rules of king Sukhamfa, Susnegfa and Sarufa faced earthquakes in 1596, 1601 and 1642 respectively. The earthquake of 1663 was so devastative that Mirjumla is believed to have fled Assam. The reign of King Rudra Singha experienced earthquakes twice in 1696 and 1749.There are historical evidences that earthquakes damaged parts of Assam in 1772, 1832 and 1848. as many as twenty destructive earthquakes of magnitudes 6~7 rocked this region during the past century. With the setting up of the Geological Survey of India in 1851 necessary instruments for measuring the magnitude and intensity of earthquakes were deployed making it possible to study the occurrences of earthquakes in a scientific manner. Since then hundreds of earthquakes of varying magnitudes and intensities have been reported from all over the region and as many as twenty destructive earthquakes rocked this region with damaging consequences. The following is a brief summary of some of the mega earthquakes of the North East.

Cachar (Assam), January1869

The Cachar earthquake of 1869 was the first significant earthquake that was studied in a scientific manner. The earthquake struck on 10th January 1869 and had its epicentre located in the Cachar region of Assam. The impact of the shock was felt over 6,50,000 square kilometres. There was heavy damage in the towns of Cherrapunji, Silchar, Shillong and Sylhet and also in Manipur. Fissures opened on the banks of the Surma river and sand vents threw up great amounts of sand and water. The epicentral tract was 30 - 45 kilometres long and 5 - 6 kilometres wide lying on the northern border of the Jaintia Hills. The hypocentre had a depth of 50 kilometres. This is the first earthquake in India for which Geological Survey of India carried out field investigations. Sir Thomas Oldham carried out the investigations. A comprehensive Report was published in 1882 as GSI Memoirs.

Date:	10th January 1869
Epicentre:	9.4 kilometers N of Kumbhir (Assam)
Latitude:	25.00o N
Longitude:	93.00o E
Origin Time	11:45 UTC / 17:15 IST
Magnitude:	7.5
Max. Intensity:	VIII

Shillong Plateau (Meghalaya) June, 1897

This was one of the most powerful earthquakes in the Indian sub-continent and probably one of the largest known anywhere. The quake wrecked havoc across south-west of the present states of Assam, Meghalaya and Bangladesh. About1542 people were killed and hundreds more injured. Damage from the earthquake extended into Kolkata where dozens of buildings were badly damaged or partially collapsed. Shaking from the event was felt across India, as far as Ahmedabad and Peshawar. Seiches were also observed in Myanmar.

Date:	12th June 1897
Epicentre:	14 kilometres ESE of Sangsik (Meghalaya)
Latitude:	25.50o N
Longitude:	91.00o E
Origin Time:	11:41 UTC / 17:11 IST
Magnitude:	Ms 8.7

It had a magnitude estimated variously between Ms 8.7 and Mw 8. The earliest report of extreme ground acceleration is recorded for this earthquake, where stones on the roads of Shillong as said to have "vibrated like peas on a drum". Recent studies also indicate that this might have been a blind earthquake because there was no surface exposure of the fracture

Previously this earthquake was thought to have been caused by a slip along north dipping fault that forms the plate boundary under the eastern Himalayas. New studies show that it originated on a south-south-west dipping fault, named the Oldham Fault, bounding the north-western section of the Shillong Plateau. During the event, the total slip on this fault, amounted to 16 metres, which is among the greatest for any known earthquake. Geodetic observations indicate that the rupture extended up to 35 kilometres into the crust and might have even cut though its base, which in this region, lies at a depth of 43-46 kilometres. The rupture of the Oldham Fault terminated at a depth of 9 kilometres from the surface of the earth, implying that this event was blind.

Post-earthquake surveys mapped large fault scarps on the western edge of the Shillong Plateau, most notably the Chedrang and Samin fault scarps. The former, which follows the Chedrang River, perhaps suggests an old line of weakness and resulted in numerous sag ponds and waterfalls as the drainage was disrupted. The Cedrang fault extended over 19km. The maximum offset recorded here was 35 feet. These faults were the result of large scale secondary faulting that accompanies blind earthquakes, which is often observed and sometimes misinterpreted as the primary rupture. The high ratio of slip to fault length implies a high static stress drop at the high end of the observed range and this is consistent with the violence of the shock, where observations indicative of accelerations in excess of 1g were noted.

The earthquake caused great destruction to many towns in Assam and Meghalaya, particularly Shillong and Guwahati, where many structures collapsed. For example, all stone works in the neibourhood of Shillong, including most of the bridges, were absolutely leveled to the ground. The stone houses and particularly the Churches were reduced to flat heaps rubles. Two 30-40 ft tall monuments of excellent cut stone work were ruined. Ekra-built buildings also got damaged. Plank buildings of wooden framework and resting unattached on the ground remained intact.

Oldham has drawn the contour line of the earthquake encompassing the known cases of severe damage to indicate the “limit of severe damage” resembling a hat. On the basis of Oldham’s descriptions another contour was drawn (Seeber & Armbruster, 1981) to show the limit intensity of VII to IX, which extends ~550km in E-W direction. This contour line delimits the intense liquefaction in the alluvial plains. The western extent of the 1897 landslides and intense liquefaction are sharply defined and abut with the 1934 Bihar earthquake landslides and “slump belt” respectively. According to them the 1897 rupture probably did not extend farther than longitude 93*E.

Landslides were reported all across the Garo Hills. The towns of Dhubri, Goalpara, Guwahati and Coach Bihar in Assam and West Bengal were heavily damaged. Earthquake fountains, some 4 feet high, were reported from Dhubri. The Jolboda and Krishnai bridges were also ruined. At Goalpara, a 10-foot wave from the Brahmaputra (possible subsidence), swept into the area, destroying the bazaar and many pukka buildings. Ground waves were reported from Nalbari, where an observer saw rice fields rise and fall as the waves passed under them. At Guwahati, the earth subsided along the Brahmaputra and several sand vents were formed. The Brahmaputra is also reported to have risen by 7.6 metres and even reversed its flow during the shock. Large scale subsidence was also reported from Muktagacha, Bangladesh. This town was constructed on reclaimed ground. . Fissures and sand blows occurred over a wide area of Assam, Meghalaya, West Bengal and northern Bangladesh. Fissures and sand blows were also reported from some parts of Bihar.

The earthquake affected both Dhaka and Kolkata. In Dhaka many buildings collapsed, many more were heavily damaged. Sand vents also occurred at many places in the city. Kolkata, was also badly affected, though to a much lesser extent than Dhaka. Walls and parapets came off many buildings, and the steeples of some churches were broken off. Damage was reported from Bardhwan, Bhagalpur, Behrampur, Comillah, Chittagong, Jamalpur, Jessore, Khulna, Monghyr (Munger), Murshidabad, Naokhali (Maijdi) and Purnea.

Shaking effects of the main shock were experienced over a wide area of the subcontinent as far as Himachal Pradesh, Myanmar and the present-day Indo-Pakistan border. At towns like Lucknow and Allahabad, the shaking was strong enough to displace crockery. In Kathmandu, trees and free standing objects swayed and people ran outdoors. To the south it was felt at Bezwada in Andhra Pradesh and in the west upto Sehore, in Madhya Pradesh. Chandeliers and lamps oscillated at Piploda and Khandwa. It was not felt in Mumbai, though instruments did pick up the disturbance. Long period effects such as water oscillations were also reported. In Ahmadabad, water in a tank was set into motion and it spilled over partitions in the tank. In Myanmar, on the Theingale River, near Tagaung, no tremors were felt but water in an old river course was "lapping along its banks" and at Thayetmyo, water in a tank began to oscillate back and forth for about three minutes, rising 18 inches on the side of the tank. Hot springs at Sitakund became more active following the quake, while those at Rajgir discharged coloured water for three days.

Dozens of aftershocks were felt in the region. At the Bordwar tea estate, a week after the main shock, the surface of a glass of water standing on a table was in a constant state of tremor. At Tura, a hanging lamp was kept constantly on the swing for 3 days. On June 13, at around 01:30 local time (LT) and again at 13:00 LT two severe shocks were felt. The earlier event was strong enough to be felt at Kolkata and as far as Sutna, which lies beyond Allahabad. Two more shocks, were felt at Kolkata, at 22:40 LT on June 13 and at 00:47 LT on June 14. Later, on June 22, at 07:24 LT, June 29, at 22:19 LT and October 2, at 20:58 LT, strong aftershocks were felt as far as Kolkata. The last event felt in Kolkata, occurred at 01:40 LT on October 9, 1897.

Meghalaya, September, 1923

A strong earthquake shook parts of south of Meghalaya, Assam, West Bengal and Bangladesh on the morning of 9th September 1923.

Date:	9th September 1923
Epicentre:	South Meghalaya
Latitude:	25.25o N
Longitude:	91o E
Origin Time:	22:03:42 IST
Magnitude:	Ms 7.1

The earthquake causes heavy damages at Mymensingh, Cherrapunji, and Guwahati. The earthquake was also felt at Barisal, Chittagong, Nagrakata, Midnapore, Srimangal, Sivasagar, Tatung, Salonah, Borjuli, and Narayanganj.

Dhubri (Meghalaya), July 1930

A strong earthquake shook parts of western Assam, West Bengal and Bangladesh on the morning of 2nd July 1930. Strong as it was the Dhubri earthquake most surprisingly but thankfully did not cause any fatalities, though a few were injured. This, in spite of the fact that it hit in the early hours of the morning. Most of the buildings in Dhubri and the surrounding areas were damaged in this shock.

It was felt as far away as Kolkata, Chittagong, Dibrugarh, and Patna. It was felt nearly all over northern-eastern and eastern India. This earthquake was followed by six major aftershocks of magnitude 6. The first three were in the immediate epicentral region south of Dhubri. The next three were in the region southeast of Goalpara, on the Assam-Meghalaya border.

Date:	2nd July 1930
Epicentre:	3.9 kms NNW of Dabigiri (Meghalaya)
Latitude:	25.80o N
Longitude:	90.20o E
Origin Time:	21:03:34.4 UTC / 03:23:34.4 IST
Magnitude:	Ms 7.1

Hojai (Assam), October 1943

At around 11 PM on the 23rd of October 1943, a major earthquake rattled northeast India. The shock had a magnitude of 6.9 (Mw). Not much is known about this earthquake as it occurred at the height of World War II when the threat of Japanese aggression on the eastern border of British India was extremely high. Doug Warr, who was stationed with a medical unit near Dimapur, gives an eyewitness account of the events of that night. “At the time I was with a medical unit stationed on the Manipur road, seven miles from Dimapur. I was awakened in the night by violent shaking - so violent that I found myself clinging desperately to the charpoy to avoid being shaken off. There was a rumbling noise. I don’t know how long it lasted - perhaps a few minutes - and then it subsided to occasional slight tremors. In the morning we discovered that there were fissures and great unevenness in what had previously been level ground, trees had fallen and buildings had been damaged. There was some damage to the Manipur road, I think to the bridges on either side of my unit, but for security reasons a complete ban was imposed on the mention of any consequences of the quake so we never heard precise details. Of course, rumour was rife and we heard lurid accounts of fissures that had opened and swallowed men and vehicles but these were never substantiated and may have been figments of somebody’s imagination. We shall never know”. Dimapur was 74.5 kilometers SSW of the epicentre. Based on this account it is possible that the MM intensity near Dimapur was VIII to IX.

Date:	23rd October 1943
Epicentre:	13.6 kms E of Hojai (Assam)
Latitude:	26.00o N
Longitude:	93.00o E
Origin Time:	17:23:17 UTC / 22:53:17 IST
Magnitude:	Ms 7.2

Arunachal Pradesh, July 1947

The earthquake of 29th July, 1947, had a magnitude of 7.7. This earthquake was felt over larger region – Assam, Bengal (upto Kolkata) & Bihar (upto Purnea).

At Jorhat in Assam water overflowed riverbanks. At Dibrugarh, Jorhat & Tezpur crack in walls & failure of electricity at Guwahati. The earthquake was also felt at Silchar, Kathmandu, Rajsahi, Krishnagar, Lasha, Cooch-Bihar, Mymensingh, Dhubri, Rangpur, Tezpur, Srimangal, Bogra, Kalimpong, Comilla, Darjeeling, Guwahati, and Purnea.

Date:	29th July 1947
Epicentre:	Arunachal Pradesh
Latitude:	28.80o N
Longitude:	93.70o E
Origin Time:	13:43:20 IST
Magnitude:	Ms 7.7

Arunachal Pradesh-China Border, August 1950

This "Independence Day" earthquake was the 6th largest earthquake of the 20th century. Though it hit in a mountainous region along India's international border with China, 1500 people were killed and the drainage of the region was greatly affected. The resultant floods were the cause of most of the fatalities aftermath of this earthquake. The initial shock was followed by thousands of aftershocks, some of which were big earthquakes enough to be reckoned.

Date:	15th August 1950
Epicentre:	20.7 kilometers NW of Tajobum (Arunachal Pradesh)
Latitude:	28.50o N
Longitude:	96.50o E
Origin Time:	14:09:28.5 UTC / 19:39:28.5 IST
Magnitude:	Ms 8.7

It had a magnitude of 8.7 and struck a relatively sparsely populated region along the Indo-China border. This earthquake is often referred to as the "Assam Earthquake of 1950".

The earthquake occurred at 19:39 PM on August 15, 1950. It was felt throughout north-eastern India and in many parts of eastern India. It was also felt throughout Bangladesh, Bhutan and Myanmar. Damage occurred in the entire region as far as Kolkata. It was felt across a wide area of the subcontinent, over an area totaling 4.5 million square miles.

There was widespread devastation in Upper Assam, the Abor Hills and the Mishmi Hills. The region that suffered the most damage to life and property was 15,000 square miles. This included the districts of Jorhat, Lahkimpur, Sibsagar and Sadiya in Assam. Dibrugarh and Saikoaghat were among the worst affected areas. Railway communications were disrupted due to damage to tracks and bridges. However, the area that suffered damage and encompassed by the isoseist VIII was nearly 75,000 square miles. There were fissures in the earth, from which water and sand was emitted. These are called sand vents and represent liquefaction due to intense ground shaking. Vast areas of land either were elevated or subsided, altering the drainage of the region.

There were huge landslides in the mountains and these dammed tributaries of the Bramaputra River, like the Dihang, Dihing and Subansiri. The latter was dammed by landslides for several days and some worst liquefaction damage was reported from the area where the river enters the plains. These were breached a few days later and resulted in serious flooding. Most of the loss of life was as a result of the flooding and not directly from the earthquake. Pilots flying over the meizoseismal area reported great changes in topography; this was largely due to enormous slides, some of which were photographed. Alterations of relief were brought about by many rockfalls in the Mishmi Hills and destruction of forest areas. 1,526 deaths were recorded, out of which 600 were from Lakhimpur and Sibsagar districts alone. In the Arbor Hills 70 villages were destroyed with 156 casualties due to landslides. Dykes blocked the tributaries of the Brahmaputra; that in the Dibang valley broke without causing damage, but that at Subansiri opened after an interval of 8 days and the wave, 7 metres high, submerged several villages and killed 532 persons. Mathur concluded that at least 5x1010 cubic metres of material was involved in the sliding. This is about 30 times of the average load of detritus carried by the river Brahmaputra annually.

F. Kingdon-Ward, a botanical explorer at Rima, very near to the epicentre, heard heavy explosive sounds. These sounds were also heard at many places in India and Myanmar, at distances of over 750 miles. Though his primary concern was getting back to India, he did confirm violent shaking at Rima as well as extensive landslides. Anders Kvale coined the term seismic seiche in 1955 to describe oscillations of lake levels in Norway and England caused by the earthquake.

This earthquake was caused due to a slip on the Jiali and Po Chu Faults in southern Xizang, along the border with northeast India. The fault plane mechanisms for this event indicates strike-slip faulting (Ben-Menahem et al. 1974) with one of the planes striking NW. Surface faulting is thought to have also occurred as a result of the quake. A recent fault plane solution by Chen & Molnar (1977) suggested a plane dipping NW with a slip in the dip direction of the plane. The earthquake was followed by a large number of aftershocks, most of which were of magnitude 6.0 or greater. These were very frequent following the earthquake and continued for many years after the main shock. Their frequency however kept on decreasing with the passage of time. The aftershock zone extended from 94 degrees east longitude to 97 degree east longitude. The aftershocks were located primarily in the central portion of themeizoseismal area, and extended considerably beyond the limit of the landslides to the north and to the southeast.

Arunachal Pradesh, March, 1954

The shock has a magnitude of 7.7 and originating from Manipur-Burma border. The shock was felt widely over whole of Assam, Bengal & parts of Bihar & Orissa. Minor damages reported from parts of Assam.

Date:	21st March 1954
Epicentre:	Manipur-Burma border
Latitude:	24.2o N
Longitude:	95.1o E
Origin Time:	23:42:17 IST
Magnitude:	Ms 7.7

Arunachal Pradesh, July 1957

Date:	1st July 1957
Epicentre:	Near Indo-Burma border
Latitude:	25o N
Longitude:	94o E
Origin Time:	19:30:20 IST
Magnitude:	Ms 7

This earthquake of 1st July, 1957 had the magnitude of 7.0 and it has the epicenter near Indo-Burma border. This earthquake was widely felt over Assam, Manipur, Tripura, East Pakistan and parts of West Bengal and Bihar. Within Assam the shock was felt at Tezpur, Halflong, Guwahati, Kailasahar, Silchar, North Lokhimpur, Rowriha, Kumbhirgram, Kohima, Dhubri, Lumding, Pasighat, Imphal, Bindukuri, Shillong, Mazbat, Goalpara and Agartala. However only Silchar (Cachar) reported minor property damage.

Silchar (Assam), December, 1984

Date:	31st December 1984
Epicentre:	SSE of Silchar (Assam)
Latitude:	24.64o N
Longitude:	92.89o E
Origin Time:	23:33:37 UTC
Magnitude:	Mw 6.0

This earthquake affected an area of about 250sq km. 20 people were killed in Cachar District and 100 were injured. Damage was of moderate nature except around Sonaimukh Bazar area. The Sonaimukh bridge over the Sonai river and a few school buildings got severely damaged. The Sonaimukh bridge was dislodged from the abutment towards SE direction as a result the bridge was closed to traffic. Two furlongs away from the said bridge , the Nitya Gopal High School and the Sonai Senior Madrassa were severely damaged. These schools were housed in traditional Assam type buildings having walls made of ikra or bamboo strips being cement plastered. Unfortunately the half brick walls were resting on the floor rather than to the foundation. The wall fell towards north. The entire desk –bench were thrown haphazardly over the floor, the ceiling fans got twisted, heavy almirah also tilted. The boundary walls of both the schools were raged to ground. A few furlongs away two mosques were also affected and in one the bell tower was thrown to a distance of about 20ft. Numerous cracks developed on the floor and walls.

Tipi (Arunachal), October, 1985

Date:	12th October 1985
Epicentre:	Assam –Arunachal Boundary
Latitude:	27.1 N
Longitude:	92.5 E
Origin Time:	
Magnitude:	M 5.3

The zone confining to MBF near Tipi experienced an earthquake of magnitude 5.3 on October 12th, 1985 at a depth of 9 km. Later, numerous events of magnitudes 3.0 <Md < 4.5 occurred in this zone at depths 10-30 km. Kameng fault is also passing vertically and meeting MBF though this point. This is one of the zones where the Himalayas change trend from E-W to ENE- WSW and gradually assume NE-SW trend. This earthquake caused extensive damage in and around Tipi .The orchid farm at Tipi and its housing colony suffered damage. The earthquake was followed by a large number of aftershocks of moderate strength.

Manipur-Myanmar Border, August 1988

This was a significant earthquake, which occurred on the Indo –Burma border. Its hypocentre was at a depth of 91km. Widespread damage was there at Jorhat, Golaghat, Dirugarh and Manipur. However, because of its occurrence at a considerable depth the effect was comparatively low.

Date:	6th August 1988
Epicentre:	Indo-Myanmar Border
Latitude:	24.149o N
Longitude:	95.127o E
Origin Time:	05:03 IST
Magnitude:	Ms 7.3

Seismogenesis of Northeastern India and the Adjacent Areas

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Abstract : *For proper assessment of earthquake hazards of an area/region geodynamics of the tectonic crustal/lithospheric blocks, especially their interactions at the interfaces and the nature of contemporary tectonic activities should clearly be understood. Intensive research on seismotectonic and geodynamics of Northeastern India and the adjacent by the author and his coworkers during the last 3 decades has led to the identification of four distinct tectonic blocks with their characteristic geodynamic evolution and present day dynamics of intra and inter-block movements in the broad settings of collision-subduction domains of the NE moving leading edge of the Indian plate in this region. Quite a few seismogenic active faults have been identified for the first time, most of which had strike-slip motion in the eastern Himalayan and in the Meghalaya Plateau sectors that produced many earthquakes. At present the Kopili fault zone seems to be locale for future major earthquake. The source fault responsible for the 1897 great earthquake has also been identified.*

Introduction

During the last two decades lot of emphasis has been put up by different Indian organizations/ institutes in instrumental monitoring of earthquakes but little work has been done to identify the seismogenic active faults/thrusts that had generated many great, large and moderate earthquakes. Thus the source faults/thrusts for many important events, viz. 1897 great Assam, 1934 Bihar-Nepal, 1950 great Mishmi Hill, 1993 Khilari etc. earthquakes have not been unequivocally established even today. Ground mapping and characterization of the contemporary active faults/thrusts, both geologically and geophysically, generating the important earthquakes is very important in assessing the future hazard potential of a particular geographical area. Sometimes scanty data and cursory interpretation of existing data without ground truth verification led to assignment of some nonexistent fault (e.g. Oldham fault; Bilham, et al, 2001) that was supposed to have produced the 1897 great Assam earthquake.

Most of the damaging earthquakes occur due to movements of the different tectonic/lithospheric blocks. Identification of active margins of such blocks as well as intra-crustal/intra-block active faults is a priori requirement for socially useful earthquake hazard analysis. The National program of GPS studies laid emphasis on crustal velocity vector without giving due consideration to the differential movements of the intra-crustal tectonic blocks. The primary task for identification of such seismogenic faults is to work out the geodynamics of the region through the geological past to arrive at the contemporary dynamics of the tectonic blocks and their interfaces, then closely map those interface to assess the present level of their seismicity. Otherwise with the present level of accuracy of location of epicenter/hypocenter in our country it is quite difficult to correlate an earthquake event with the known fault in the area.

Having these ideas in mind a preliminary attempt was made by the author to broadly identify the major seismogenic faults in India, especially of the shield areas (Nandy, 1995) that may form a guideline for future research in this domain. The author and his coworkers have carried out extensive research in seismotectonic of the Northeastern India and the adjoining areas over a period of 30 years resulting in proper understanding of geodynamics of the region and identification of many seismogenic active faults that had been the source of many important earthquake events.

The whole of Northeast India has been categorized as zone V in the seismic hazard zone map of India (IS1893:2002), Though the region is located in the intense seismic zone of the world it is high time that the region should be subdivided into number of sub-zones having relative hazard potential based on the proper and detailed seismotectonic data to help the accelerated developmental activities for this backward region.

Northeastern India and the adjoining areas fall in the junction of the northern collision and the eastern subduction interface of north-drifting Indian plate causing intensive seismic activity in the region. Four major distinct tectonic domains characterize the region. They are (i) Eastern Himalayan mobile belt; (ii) Mishmi Hill block; (iii) Patkoi-Naga-Chin-ArakanYoma (Indo-Myanmar) mobile belt and (iv) Meghalaya-Mikir Hill block. Each of these domains has its own evolutionary history, characteristic pattern and geometry of inter and intra-domain dynamics of movements producing characteristic seismicity.

Eastern himalayan mobile belt, trans-himalayan region and misahmi block

This domain is characterized by post-collision N-S crustal shortening by (i) vertical plane strain with the development of southward migrating thrust fronts, viz. Main Central Thrust, Main Boundary Thrust and Frontal Foot Hill Thrust systems; (ii) followed by east and southeastward extrusion of wedge shaped crustal block along E-W/NW-SE giant strike-slip faults in Tibet and main land China such as Kunlun, Altyntag, Kangting and other faults that led (iii) to the origin of the N-S graben across the axial zone of the main Himalaya and NW-SE and NE-SW conjugate strike-slip fault in the main Himalayan sector being the most contemporary active tectonics in the region. The extrusion tectonics in the main land China are very active now with the NE-SW thrust front in eastern China e.g. Long Men Shan thrust that generated the 12.05.2008 Sichuan Province earthquake (M 7.8) killing 69,000 people (see fig. 7 in Nandy, 2001).

It was contemplated by many researchers that most of the Himalayan earthquakes were generated due to movements along the broadly E-W thrust systems but in the eastern Himalayan area most of the earthquake events were produced by the active strike-slip fault lying athwart to the Himalayan trend. The 1988 Bihar-Nepal earthquake and 1980 Gangtok earthquake, both having magnitude greater than 6, had well constrained focal depth of 60km and 47km respectively and both yielded clear strike-slip focal mechanism solutions (Dasgupta, et al, 1987). These two earthquakes could have not been generated by thrust movements, nor that had been possible for any thrust in the Himalayan settings to produce such relatively deep focus earthquakes.

Seismotectonic analysis of the eastern Himalayan zone (Dasgupta et al, 1987 and Nandy, et al, 1991) has clearly indicated that many of the transverse strike-slip faults are at present active producing most of the earthquake events in this zone. The most important of them, from west to east, are East Patna, Kanchen Dzonga, Yadaon Gulu (graben), Tista, Jamuna, Dudhnoi, Kulsi, Gyau (graben), Kopili and Bomdila faults (figs.3 & 4)). Focal mechanism solutions for well constrained events occurring along these faults yielded predominantly strike-solutions but the events occurring along the central Himalayan graben structures gave normal solutions. It may be mentioned here that the Dudhnoi and Kulsi faults cutting across the Meghalaya Plateau and Brahmaputra valley also traverse across the frontal Himalayan fold and thrusts belt.

The Mishmi block is characterized by NW-SE trending thrust/reverse faults belt formed mainly by diorite-granodiorite complex of rocks with a belt of metamorphic rocks along the foot hills. Four important NW-SE thrusts/reverse faults traverse the block. They are, from foot hills to the higher Himalayan zone, Mishmi thrusts, Tidding suture, Lohit thrust and Po Chu fault. The frontal Mishmi thrust overrides the ENE-WSW trending frontal thrust belt of the Indo-Myanmar mobile belt in the Noa Dihing valley of Tirap district of Arunachal Pradesh. The earthquake events occurring in the southeast extremity of the Mishmi thrust at present yielded right lateral strike-slip faulting along steeply dipping NE to ENE nodal plane (fig. 4). Other events occurring right inside the Mishmi Block yielded strike-slip solutions indicating thereby that the present tectonic transport in this area is mainly through strike-slip motion. It is interesting to note that the 1950 great earthquake (M 8.6) occurred in the Po Chu fault zone located in the northeast extremity of the Mishmi block. This event yielded both dextral slip along NW nodal plane and also thrust events by different workers (for detail see Nandy, 2001).

Patkoi-Naga-Chin Hill-Arakan Yoma (Indo-Myanmar) Mobile Belt

The Indo-Myanmar mobile belt and the contiguous Andaman-Mentawai arc was formed in response to the east/northeast directed subduction of the Indian lithospheric plate below the Myanmar-Andaman-Sumatra plate since the Cenozoic period. This process of subduction along a very long interface has remained active even today making the entire belt highly seismic.

In this vast linear tectonogeologic set up active regional fundamental thrusts/faults experiencing brittle failure are subduction interface of the Indian plate and the overriding Myanmar-Sumatra plate and other associated structure, geometry of which has been worked out by many workers (Nandy, 2001; Dasgupta et al, 2003; Satyabala, 2003 and many others). 1200km long rupturing along this interface in the Andaman-Sumatra domain on the 26th December, 2004 produced the great 9.2 magnitude earthquake that generated a devastating tsunami killing more than 2 lakhs people. Other important regional active structures are N-S Shan-Sagaing strike-slip fault delimiting eastern boundary of Central

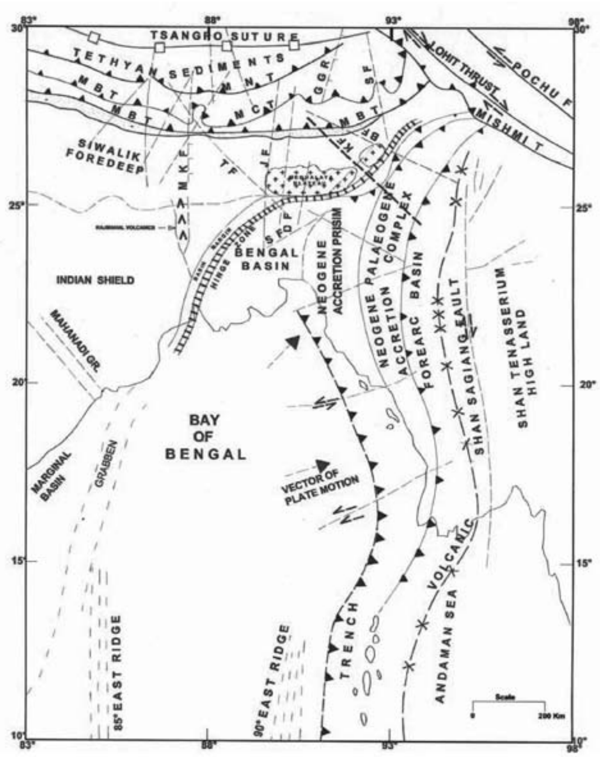

Figure 1: Generalised Tectonic Map of India and the adjoining region. MCT-Main Central Thrust, MBT Main Boundary Thrust, MNT-Main Northen Thrust, YGR-Yadong Gulu Grabben, GGR-Gayo Grabben, SF-Siang Fracture, MKF-Malda Kisangunj Fault, TF-Tista Fault, JF-Jamuna Fault, DF-Dudhnoi Fault and Dauki Fault, KF-Kolpli Fault BF-Bomdila fault, SF-Sylhet Fault, EBT-Eastern Boundry Thrust, GR-Grabben, PL-Plateau, T-Thrust, Asterisks indicate Volcano

Figure 2: Tectono-Geological Map of North-Eastern India and adjoining region (For details, see Nand 2001)

Myanmar molasses basin; Central Myanmar volcanic line passing southward through Narcondom and Barren islands to the coastal zone of Sumatra; the Eastern Boundary thrust representing the surface trace of subduction interface in onshore areas; Basin Margin fault of Paleogene outer arc demarcating the eastern boundary of the Surma basin; the frontal thrust belt of the Upper Assam basin (belt of schuppen) and number of deep seated cross faults (figs.1, 2 and 3). The Neogene outer arc represented by Surma basin is delimited to the northwest by seismically active steeply dipping NE Sylhet fault that passes along the northeast corner of Bangladesh in Bengal basin.

Meghalaya Plateau and Mikir Hills

This is a block uplifted plateau buttressed in between the Himalayan mobile belt and the Indo-Myanmar mobile belt that represent northeastern-most Indian shield element. This domain has geological history from Proterozoic to Recent. Central and northern parts of the plateau are occupied by Proterozoic granite gneiss and Proterozoic-early Paleozoic granite intrusives. The southern margin of the Plateau contains least disturbed Cretaceous to Recent sediments.

Most important structure in this domain is the 200km long E-W vertical Dauki fault that defines the southern margin of the Plateau. Though this fault had remained tectonically active since Cretaceous till the Quaternary, having cumulative vertical throw of 18km, forming the conduit for the effusion of Cretaceous Sylhet trap volcanics, is seismically dormant at present (Nandy, 2001). Another fundamental facture running NE-SW across the Meghalaya Plateau and Mikir Hills acted as the conduit for emplacement of the Cretaceous ultramafic-carbonatite complex. Present day active faults in this domain are N-S Dudhnoi and Kulsi faults traversing the plateau from Sylhet plain to the Himalayan foot hills; NW-SE Kopili fault running between the Meghalaya Plateau and Mikir Hills and the NW-SE Bomdila fault grazing the eastern limit of Mikir Hills that also cuts through the Indo-Myanmar mobile belt in the southeast and frontal Himalayan thrust/fold belt in the northwest.

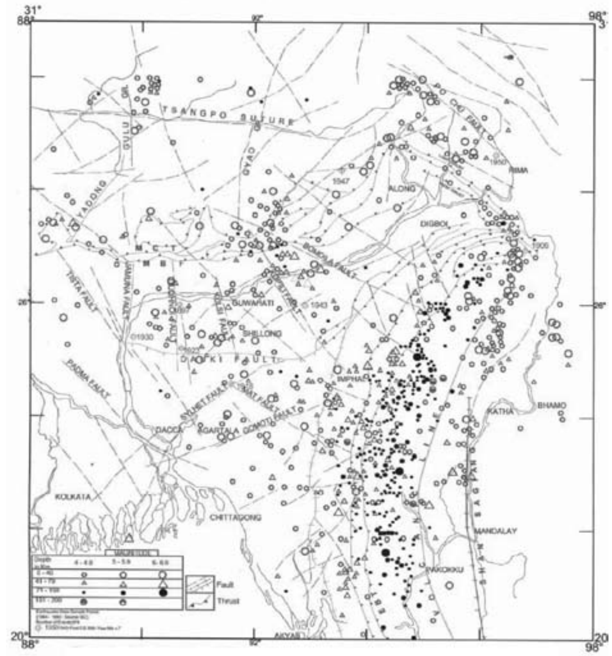

Figure 3: Seismicity Map of Northeastern India and adjoining region. Earthquake Data from 1964-1993 (Source ISC)\Plotted on the tectonic map of the area for detail see Nand,2001.

Seismicity and a few of the Identified Causative Faults/ Thrursts

Northeastern India and the adjoining areas fall in the intense seismic belt of the world. Out of 5 great earthquakes experienced by India during the past, 3 events fall in this region including the 1934 Bihar-Nepal earthquake. Besides, 11 large earthquakes (M>7) occurred in this region during the period from1869 to 1947. Of these 5 belonged to the Indo-Myanmar subduction zone, four in Meghalaya Plateau and Mikir Hills areas, 1 in the Siang fracture zone of the eastern Himalaya and one in the northeastern corner of Bengal Basin in Bangladesh (figs. 3 and 4). The area between 88º and 98º east longitude and 20º and 31º north latitudes has experienced 974 earthquake events

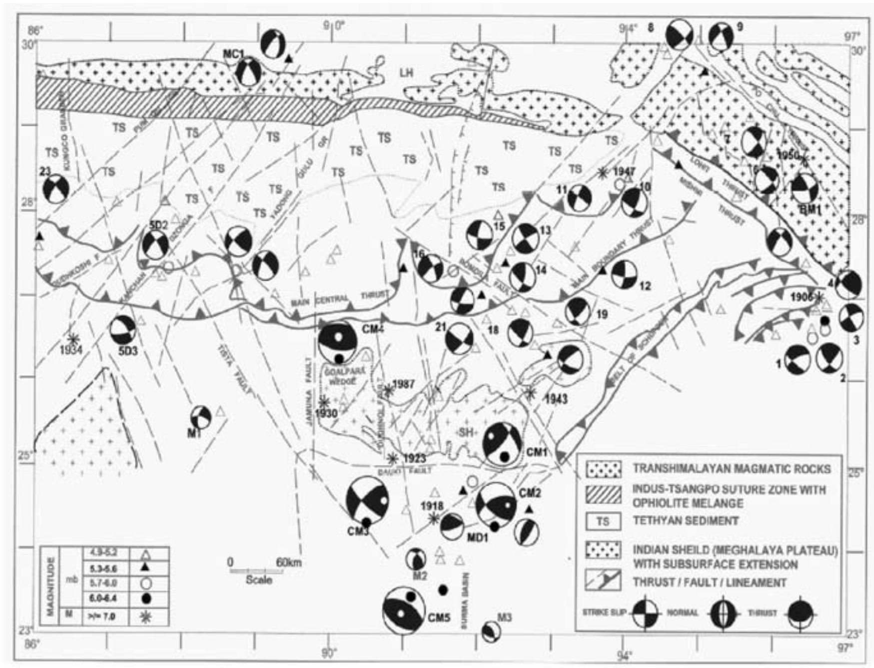

Figure 4: Sismotectonic Map of Northestern India and adjoining areas (except for Indo-Myanmar region). Earthquake data sample period 1963-1984 for mb>49. A few local mechanism solutions of later date have also been incorporated. 39 focal meachanism solutions are schematically shown on the tectonic base. LH-Ihsa, SH-Shilong, F-Fault, G-Grabben, TS-Tethyan Sediment solid dots are pressure axes and hollow circles are tension axes in CM1 and CM5

having M≥ 4 during the period from 1964 to 1993 (source: ISC, fig.3). It is interesting to note here that first scientific studies of earthquakes in India were undertaken here for the 1869 Cachar earthquake (M>7) by T. Oldham (Mem. GSI, vol. 19, pt.1,1882) having its epicenter on the Kopili fault zone, and its shocks were felt severely at far off places like Kolkata.

Considering the past and present level of location accuracy of earthquake epicenters it appears that the pattern of seismicity in this region is diffused except those occurring along the Indo-Myanmar subduction zone. Even the close network of monitoring seismicity by RRL, Jorhat, Assam in the area revealed the same diffused pattern. Though in the recent past and at present lots of studies have been made and are being made in monitoring seismicity in this terrain to understand the nature of earthquakes, many questions considering the exact location and nature of earthquake sources based on contemporary tectonics have remained largely unsolved. However, based on ground geological data and analysis of seismicity pattern attempts have been made to broadly correlate the source zones of the major earthquakes by the author and his coworkers (Das Gupta and Nandy, 1982; Nandy, 1986; Nandy and Das Gupta, 1991 and Nandy, 2001).

A few of the active seismogenic faults responsible for generating some important events are as follows:

NE-SW east Patna fault and Kanchen Dzonga fault had been the source for the 1934 and 1988 Bihar-Nepal and 1980 Gangtok earthquakes through strike-slip motion. 1930 Dhubri earthquake (M>7) was produced by N-S Jamuna or Dhubri fault that passes along the western margin of Garo Hills. NNW-SSE Dudhnoi fault traversing from the Sylhet plain, cutting across the Meghalaya plateau and then passing in to the fold belt of the eastern Himalaya had generated the 1897 great Assam earthquake(M>8.5) and 1943 events (M>7) through strike-slip motion. NE-SW trending Sylhet fault, south of Meghalaya Plateau, was the source of the 1918 Srimangal earthquake (M>7.6) that yielded high angle reverse focal mechanism solution. The NW-SE Kopili fault zone produced the 1869 Cachar (M>7.5) and 1942 (M>7) earthquake events. Focal mechanism solutions for well constrained events in this fault zone yielded strike-slip solution along steeply dipping faults (fig.4). The Bomdila fault has also generated quite a few earthquakes through strike-slip motion. The 1950 great Mishmi Hill (Assam) earthquakes (M>8.6) occurred due to strike-slip motion along NW-SE Po Chu fault (Nandy, 2001; figs 3 and 4).

Source of 1897 Great Assam earhquake (m 8.6)

As discussed in the foregoing it is argued that the earthquake was generated due to strike-slip motion along the NNW-SSE Dudhnoi fault. But Bilham and England (2001) has postulated an E-W fault, Oldham fault, along the northern margin of the Meghalaya plateau which supposed to have generated the 1897 event based mainly on the results of post earthquake revision geodetic surveys (1897-98) across the plateau covering 65km length, occupying the previous triangulation stations (fig.5) though there is no physical existence of such fault. Unfortunately some of our researchers are influenced by the postulation of Bilham and England and trying to correlate their observations with that of Bilham and England (Rajendran, et al, 2004). Therefore, it is felt necessary to discuss the issue in the light of the observations of R. D. Oldham of GSI and Major Burrard of Survey of India on the revised triangulation surveys carried out by Bond (Appendix G; Mem. GSI, vol. 29, 1899).

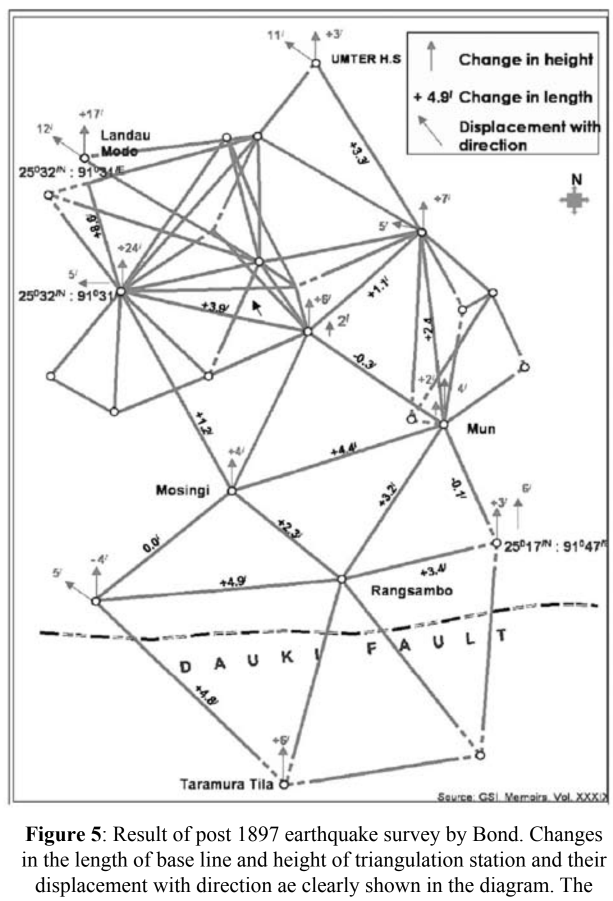

Figure 5: Result of post 1897 earthquake survey by Bond. Changes in the length of base line and height of triangulation station and their displacement with direction ae clearly shown in the diagram. The distance from Taramura Tilla to Umter is 65Km

Oldham stated that no reliable base was consequently forthcoming for the computation of Bond's observation. This might had been attributed to a compression of the hills in a meridonial direction. Burrard observed that there was increase in compression southward. Stations Mautherrichen (24ft) and Landau Modo (17ft) situated on the crest of conspicuous fault scarp; second one close to two sag pools formed by distortion (fig.5). Refraction was liable to introduce much more error in the survey work into vertical angle than in the horizontal angle. These views clearly indicate that N-S compression had been due to strike-slip motion in the same direction.

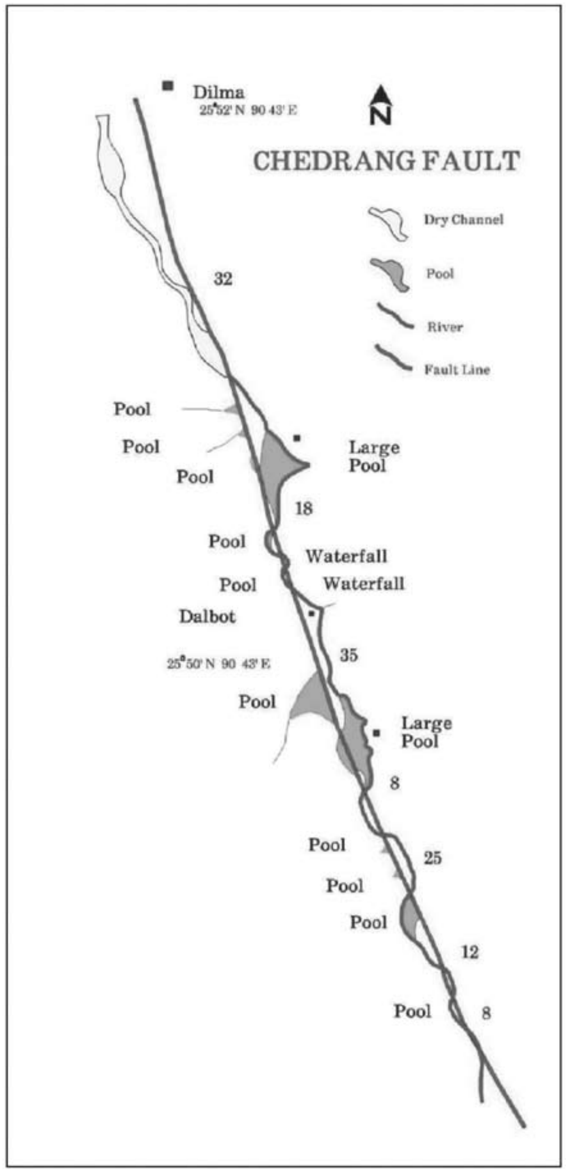

Figure 6: Sketch Map of Cherdang fault (Oldham 1899) showing development of may sag ponds and pressure ridges, characteristics of strike-slip fault

After the detailed investigation of this event Oldham (1899) enunciated the theory that the earthquake was caused by north dipping thrust plane measuring 160km in length and 80km in width at a depth of 8 to 14km and dipping towards north, drawing inferences from the thrust tectonics of Scottish Highland and Scandinavia, though he clearly stated simultaneously that the epicentral tract ran in N-S narrow zone from the Sylhet plain of Bangladesh to the high hills of Bhutan Himalaya cutting across various geological milieu lying just east of 91° meridian (page 169 of Oldham, 1899). These field observations went contrary to his E-W thrust hypothesis. Perhaps, guided by the thrust hypothesis of Oldham, subsequent workers like Seeber and Armbuster (1981), Khatri (1992) and Molnar (1987) and others had visualized a northerly dipping mid-crustal shallow active thrust bellow the Meghalaya Plateau that was supposed to join E-W vertical Dauki fault. It is interesting to note here that Oldham (1926) himself had revised his idea of existence of a mid-crustal causative thrust as he later realized that such interpretation was not satisfactory and not consistent with facts, nor were able to account for some of peculiarities of distribution of intensities of the earthquake shocks. Cause of intense destruction and ground distortion along a long narrow

N-S band was finally correlated by him with the movement along a deep seated N-S fault that is co-relatable with the Dudhnoi fault. Unfortunately, none of the later workers including Bilham and England (2001) have referred to the revised and updated postulation of Oldham (1926). Moreover, the N-S physiographic section drawn by Bilham, et al (fig. 3 of 2001) is not factually correct as it does not corroborate with topographical and geological ground truth (Nandy, 2005). The pattern in the post earthquake changes in level and co-ordinates of the different survey stations could be best explained by strike-slip motion along the Dudhnoi fault (Nandy, 2001).

During the 1897 great earthquake a few co-seismic faults had developed. The most important of these was the 20km long NNW-SSE Chedrang fault (fig.6) running from the head water of Chedrang river through Dalbot, Dilma and Jira in Assam plain with vertical throw varying from 0.60m to 10.60m, up throw being always to the east. The fault plane wherever visible appears to be vertical. But if the fault is reviewed in the context of the characteristics of strike-slip fault it is seen to be accompanied by pressure ridges and sag ponds on either side (fig.6). This fact also corroborates with the major strike-slip motion along the Dudhnoi fault that generated the 1897 great Assam earthquake.

Concluding Remarks

1. For mitigation earthquake hazard all seismogenic faults in the area should be properly identified and mapped in 3D. This is also required for future development planning and construction of life line structures.
2. From the Seismotectonic analysis it appears that the Kopili fault zone may form the locale for future large earthquakes.
3. There is also chance in rupturing along the on land domain of the Indo-Myanmar subduction zone after the 2004 great event in the off shore areas.
4. One must be careful to lay emphasis on the so called Oldham fault for future studies in this area.

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Earthquake Gology, Geomorphology and Hazard Scenario in Northeast India: An Appraisal

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Abstract : *Knowledge driven awareness, technology driven mitigation measures and community driven preparedness when integrated with development activity would constitute the ways and means for Disaster Mitigation. This would also narrow down the communication gap between the developer and beneficiaries, which is necessary to reduce time and cost overrun for infrastructural projects in geopolitically sensitive areas. During the 80 years time span between 1869 and 1950 eight large earthquakes struck northeast India. While the earthquakes of 1947 and 1950 occurred in the Himalaya and Mishmi domain respectively, the other six locates in and around the Shillong-Mikir Hills. Epicentral location and magnitude of these earthquakes are: i) 10th January 1869, 25.50N: 93.00E, Mw 7.38; ii) 12th June 1897, 25.50N:91.00E, Mw 8.03; iii) 8th July 1918, 24.25N: 91.70E, Mw 7.1; iv) 9th September 1923, 24.94N: 90.32E, Ms 7.1; v) 3rd July 1930, 25.80N: 90.20E, Mw 7.09; vi) 23rd October 1943, 26.00N: 93.00E, Mw 7.1; vii) 29th July 1947, 28.50N: 94.00E, Mw 7.3; and viii) 15th August 1950, 28.50N: 96.50E, Mw 8.6. Available published document indicate that earthquakes that occurred within or surrounding the Shillong-Mikir Hills are unique to the plateau and un-related to the Himalayan tectonics. Additional data are required to characterize the Dauki, Oldham, Brahmaputra, Dhubri (Jamuna) and Kopili faults. Geomorphic signatures of contemporary deformation are abundant in the frontal Himalaya, Mishmi and Belt of Schuppen. Three such sites are short-listed for attention and geologic probe. Presence of distinct young fault scarp in the Ultapani- Lalbhita sector in the Assam- Bhutan border attests to occurrence of late Pleistocene- early Holocene large earthquake; while for the Bhareli Dun type valley and Manabhum anticline segments, morpho-tectonic and other geologic-geodetic studies required to tag the deformation history.*

Introduction

Seismic Hazard Assessment (SHA) is a broad canvas within which separate experts contribute but with a common goal of reduction in earthquake triggered disaster. It is in the area of evaluating the hazards where earth-scientists make their primary contribution, whereas, the engineers, planners, public officials, and social scientists are more concerned with evaluation and mitigation of risk. Impact of disaster can only be combated effectively if we have a rational and objective understanding of the cause and processes of earth system science. Knowledge driven awareness, technology driven mitigation measures and community driven preparedness when integrated with development activity would constitute the ways and means for Disaster Mitigation.

In various public gathering (workshop/ awareness program on earthquake hazard etc), I often raise a few questions primarily for face reading of the audience and their response, if at all. The questions are like: Any idea on where and how earthquake occurs? What is the seismic status of the region/ area where you live? Do you know that earthquakes cannot be predicted in the sense that it is socially useful? Have you thought that even if short-term forecasting for a large earthquake is issued one cannot save properties if it has not followed anti-seismic design code? Surprisingly so far as my experience goes, the common people are clueless to such queries, without whose involvement SHA and disaster mitigation strategies will remain on the desktop of scientists and engineers. What I mean to convey is that government agencies, major industrial houses, hydroelectric and nuclear project authorities etc are aware of the scientific and technological advances being made and take recourse to expert intervention for earthquake hazard and risk mitigation but what happens to the common-man strata that are not conversant with the sophisticated seismic hazard and risk mitigation products. After all it is the common man's life and property that mostly gets destroyed in earthquakes. Awareness on the intensity level of seismic hazard in different parts of the country and availability to user-friendly earthquake resistant design code, data, information and map products, are the key issues that needs addressed. Knowledge driven awareness would also narrow down the communication gap between the developer and beneficiaries, which is necessary to reduce time and cost overrun for infrastructural projects in geopolitically sensitive areas.

Northeastern Region (NER) consists of eight States with a total area of around 262,179 sq km and population of 39 million (2001 census). Population density (person/ sq km in 2001) of Assam and Tripura is close to the national average of 324; the population density in other States is however below or around 100. About 20% are urban population (except Mizoram where it is 50%) which is rapidly growing and adding to the vulnerability in the absence of any techno-legal regime. In the event of any of the major NER earthquakes repeat, the consequences will certainly be disconcerting considering the current exposure of population and immoveable assets within the epicentral tracts of these events. Based on the 2001 census data, casualty figures estimated (Wyss, 2005) for repeat events of 1897 and 1950 are 90,000 and 40,000 respectively. Similar estimated human loss may range between 25,000 and 150,000 for scenario Himalayan earthquakes that may locate in Bhutan or Arunachal Pradesh.

Earthquake Geology and History

The last decade of the 20th Century was the International Decade for Natural Disaster Reduction (IDNDR). Geological Survey of India (GSI) took up the ambitious project of compilation of all relevant data related to earthquake hazard and published ‘Seismotectonic Atlas of India and its Environs’ in the year 2000 with database up to the mid-nineties. These maps are being widely used by various agencies in India and abroad as base document for different downstream studies. Wealth of ground geological, geophysical and seismological data generated during the last one and half decade needs to be compiled and the Atlas updated. Out of 43 SEISAT maps, 8 deals exclusively on the earthquake geology and hazard of northeastern India and surrounding countries. The region is one of the most seismically active belt of the world with Himalaya and the Indo-Burmese fold-thrust packet from the N/NW and E/SE respectively squeezing the Brahmaputra valley with its crystalline basement between the Main Frontal Thrust (MFT) and the Naga Thrust (NT); from the exposed Mikir hills the basement plunges to the northeast and lies below 6.5-7.0 km of Tertiary sediments near the Mismi front. The 250 km x 100 km stretch of Assam shelf between the Himalayan frontal belt and Belt of Schuppen, up to the Mishmi frontal thrust is relatively less seismic compared to the area located further southwest encompassing the Meghalaya Plateau- Mikir Hills segment.

During the 80 odd years between 1869 and 1950, northeast India witnessed several large to major (M ≥ 7.0) earthquakes (Figure 1). Except the 1950 Great Assam earthquake that locates on the plate margin and the 1947 Arunachal Himalaya earthquake, the other events originate from within 100-150 km south of the Himalayan deformation front (Main Frontal Thrust). All the six earthquakes of 1869, 1897 (great earthquake), 1918, 1923, 1930 and 1943 locate from within the Shillong-Mikir massif or immediate south of it. The westernmost earthquake located close to the 90° meridian, is the Dhubri earthquake of 1930 and the easternmost event is the north Cachar earthquake of 1869; while the southernmost 1918 Srimangal [in Bangladesh] earthquake located on or north of 24.50 degree latitude. None of these earthquakes are related strictly to the Himalayan tectonism, a concept which we proposed in the early eighties. I quote (from Dasgupta and Nandy, 1982); A careful review of data reveals that the seismicity in the area south of the Main Boundary Fault and west of the Arakan Yoma are not correlateable with the tectonics of the eastern Himalaya and the Indo-Burmese mobile belt. This finding leads to the proposition that all major earthquake foci located within the Meghalaya plateau originated through tectonic activity along structural elements unique to the plateau area itself. In the same paper we put forward for the first time seismotectonic arguments to delineate the Jamuna Fault, the Sylhet Fault, the Kopili Fault and the Brahmaputra Fault, apart from discussing the nature and activity of the Dauki Fault.

The Great Earthquake of 1897 and the Dauki Fault

The concept as proposed above however did not impress the earthscience community because of the attractive model proposed by Seeber and Armbruster (1981) explaining the cause of all the four great Indian earthquakes (1905, 1934, 1897 and 1950 from west to east) as detachment thrust earthquakes. The impact of this publication on the geodynamics, seismotectonics and SHA for the Himalaya in general and NER in particular was enormous.

From an exposed sub-vertical fault system with variable dip and geological slip-rake [see among others; Evans (1964), Murthy et al (1969), Nandy (2001)], the Dauki Fault became considered to be a shallow north dipping thrust fault of a nature similar to the Himalayan frontal thrust. Seeber and Armbruster (1981) proposed a rupture dimension for the 1897 earthquake to the order of 550 km (E-W) by 300 km (N-S) and also attributed the same mechanism to explain the 1943 and 1947 earthquakes occurring in the so called seismic gaps between the 1897 and 1950 earthquake ruptures. Various publications followed, dealing with tectonics and seismic hazard of this domain and all implicitly or explicitly attesting to the thrust tectonics for the Dauki Fault vis-à-vis the 1897 earthquake, an idea originally expressed by Oldham (1899) but with cautions; Though apparently the most probable this is not the only possible hypothesis (Oldham, 1899, p. 167). The rupture area of the great earthquake was brought down to the order of 170 km x 100 km (Gahalaut and Chander, 1992) within depths from 15 km (at the Dauki front) to 23 km beneath the Brahmaputra valley. These authors proposed a midcrustal detachment, a low angle thrust fault responsible for the 1897 earthquake, which is different from the shallower detachment of Seeber and Armbruster (1981). Chen and Molnar (1990) give a succinct summary of the problem in their paper on 'Source parameters of earthquakes and intraplate deformation beneath the Shillong Plateau and northern Indoburman Ranges'; They initiate the discussion as; There is no unanimity about the origin and tectonic history of the Shillong Plateau, but two ideas, which are not mutually, exclusive, prevail. These points of view center on the Dauki fault, which bounds the southern edge of the Shillong Plateau. But then at the end supports the prevailing view as; but there is a consensus that this earthquake probably involved largely thrust faulting on a plane dipping gently northward. In one of our contribution (Nandy and Dasgupta, 1991) we observed that the Shillong Plateau was seismically less active than commonly presumed and the 1897 earthquake was not related to the activity of the Dauki fault. The entire concept on the geodynamics of terrain which we are discussing was due for a drastic change with the publication of another important contribution by Bilham and England (2001). The origin of the Shillong Plateau vis-à-vis that of the great 1897 earthquake was put forward; they modeled a ESE-WNW trending 110 km long buried reverse 'Oldham Fault' at the northern end of the plateau, that dips 57° towards SSW. A slip of 16m on this prodigious fault lifted the northern edge of the Shillong Plateau at least by 11m during the 1897 earthquake. The steep dip nature of the Dauki Fault was however re-instead to develop the pop-up origin of the Shillong Plateau. Several articles since published supported the existence of a south dipping fault bordering the northern margin of the plateau. The contribution by Rajendran et al (2003) is worth mentioning who while attesting for a steep south dipping fault located north of the plateau finds evidence to place it further north along the course of the mighty river and referred it to 'Brahmaputra Fault'. This is the same Brahmaputra Fault which we designated (see map and section in Dasgupta and Nandy 1982) 20 years before; though our projection of the fault as steeply dipping to the north was based on very scanty hypocentral data. Nevertheless the important aspect that comes out from the above discussion and bears implication for SHA is that seismotectonics of the Assam shelf along with the Shillong-Mikir massif have to viewed differently and I take the liberty to quote from Rajendran et al (2003); The Shillong Plateau bounded by major faults behaves as an independent tectonic entity, with its own style of faulting, distinct from the Himalayan thrust front, a point that provides fresh insight into the regional geodynamics. This statement echoes our assessment referred above. Traditionally the epicenter of the earthquake is placed at 26.00N [sometimes 25.90N]:91.00E; Ambraseys and Douglas (2004) has revised the original isoseismal map of Oldham (1899) and refined the epicentral location to 25.50N:91.00E and estimated the magnitude Mw 8.03.

The Great Assam Earthquake of 1950

This is the strongest earthquake among all the Indian great earthquakes. This is located in the Indo-China border and must not be clubbed under the same tectonic-mechanism of the 1905 and 1934 great earthquakes (after Seeber and Armbruster, 1981); the 1897 has already been separated out

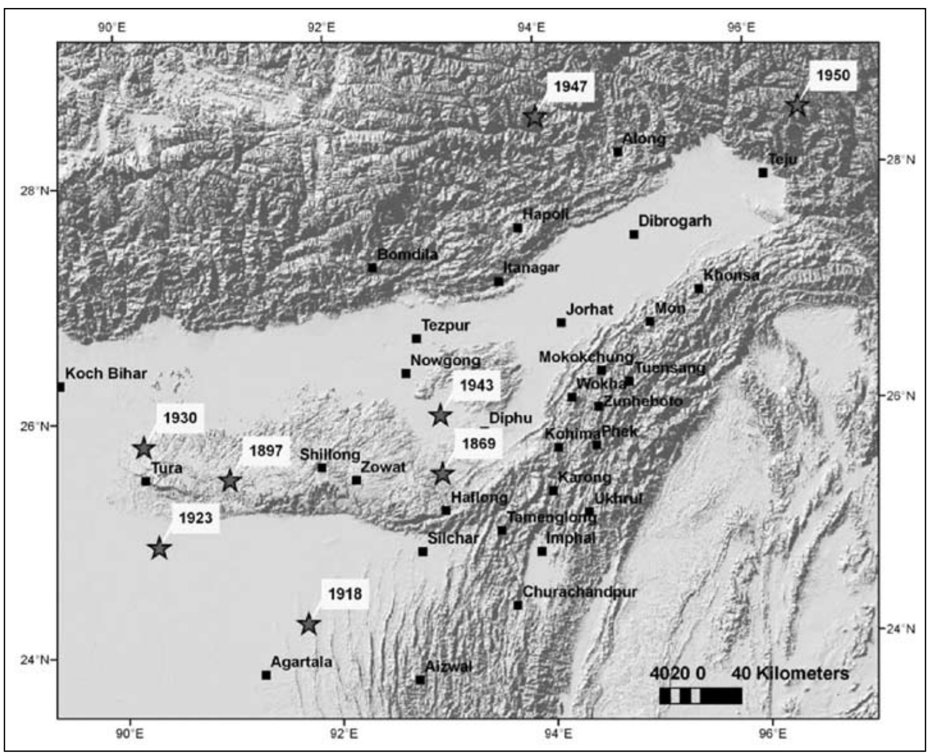

Figure 1. Location of Eight Major Earthquakes in NER that occurred between 1869 and 1950

and our assessment for the 1934 earthquake is also different (see Dasgupta et al 1987; Dasgupta, 1993 and also Maggs, 1988). The epicenter of the1950 earthquake is located at a place 'Rima' with slightly different locations given by different agencies; 28.50N:96.50E, 28.50N: 96.70E or 28.70N: 96.60E. Relocation (Endgahl and Villasenor, 2002) places the epicenter at 28.50N: 96.50E with magnitude Mw 8.6 while Ambraseys and Douglas (2004) place it at 28.70N: 96.60E with magnitude Mw 8.44. This is a major dextral strike-slip earthquake (Ben-Menahem et al, 1974) originating from the Mishmi block and related to the Po-Chu Fault (Ni and York, 1978); Chen and Molnar (1977) however preferred for a thrust fault mechanism. Additional details on this earthquake are posted in *http://www.scribd.com/geology1950 and http://sites.google.com/site/indiaquake.*

North Cachar Earthquake of 1869

The North Cachar Hills earthquake occurred on 10th of January 1869, Sunday. The earthquake was distinctly felt from Patna in the west to northern Burma in the east; in the south it was felt up to locations south of Calcutta and Chittagong; in the north from Darjeeling to Dibrugarh. The earthquake was damaging in the region from Dhubri to east of Imphal and covering areas between Nowgong and Silchar. An account of this earthquake is published in Memoirs of the Geological Survey of India (Oldham, 1883), the first systematic field documentation of any Indian earthquake. Part manuscript of this was after Thomas Oldham and the remaining added by his illustrious son R.D. Oldham. Prior to the GSI document two more articles were published by Captain Godwin-Austen (1869a, b) who was camping at the epicentral tract in connection with topographical survey. Origin time of the earthquake is around 17.00 hrs (IST) and the magnitude derived by Ambraseys and Douglas (2004) is Mw 7.38 with epicenter located at 25.50N: 93.00E. Oldham located the seismic vertical at 26.00 N: 92.66 E. In any case this crustal event is located within the Dhansiri-Kopili Fault zone, probably where this meets Belt of Schuppen, north or northeast of Haflong.

Kopili Valley Earthquake of 1943

Due to the ongoing 2nd world war very little or almost no information is available for the large earthquake of 23rd October, 1943 whose epicenter was located near Hojai in the Kopili valley, Assam. The epicenter of this earthquake is near 26.00N: 93.00E (see Nandy and Dasgupta, 1991; Dasgupta et al, 2000) and related to the activity of the Kopili Fault; and not 26.80N: 94.00E as given in some documents including that of Ambraseys and Douglas (2004). The latter location is close to west of Jorhat right on the Brahmaputra River over the Assam shelf, an area which is otherwise known for its feeble seismicity. While there is an urgent need to research out descriptive account for this earthquake from indigenous sources in Assam, I reproduce some description right from Jorhat; and this do not indicate that the epicenter of any earthquake of magnitude ≥ 7.0 was near Jorhat.

……We continued on and arrived at Jorhat, India, 11 October1943.

I was assigned to shipping and receiving in the Air Corps supply section. While at Jorhat we had English tents pitched on cement slabs for a floor. There were trenches dug between the rows of tents. One night I just fell asleep and awoke thinking I was having a nightmare. I called to one of the guys, Troop from Lancaster, PA and asked him if he was awake. He answered and asked me what was going on. Our mess kits fell down on the cement floor; our cots were bouncing and the floor rolling. We did not know what was going on. There was a fellow from California sleeping on the opposite corner and when he woke up he ***stated that we were having an earthquake****. This was my first experience with an earthquake. He yelled for us not to go to the trenches but to just stay where we were. It lasted only a few minutes but it seemed like a long time.* ***Mahatma Gandhi was being held as a prisoner in the jail in Jorhat at that time****. When we got a chance to go to the town of Jorhat we saw the damage the earthquake had done to the brick buildings and the wall at the prison* [SSgt. William Jacobey]*.

Another short description states;

While at the station near Jorhat, an earthquake struck*. The station was not damaged and some of the men slept through it. I was having 'toddy' with the tea planter in his bungalow with the GI malaria control sergeant. We were sitting at the dining room table with a kerosene lamp on the table. The three of us went across the verandah and out in the yard. The lamp* ***fell over but we were able to get the lamp upright before a fire started****. We wound up at the Planters Club where the bar was still open* [Wilmur M. McMillan]*.

On the other hand the Centennial Earthquake Catalogue (Endgahl and Villasenor, 2002) locates the 1943 earthquake at 26.00N: 93.00E with magnitude Mw 7.1. Thus both the 1869 and 1943 earthquakes are associated with the activity of the Kopili fault. That the Kopili fault zone is seismically very active has otherwise been documented in a number of articles including those by Kayal et al (2006).

Arunachal Himalaya Earthquake of 1947

There is another large earthquake of Mw 7.3 (Endgahl and Villasenor, 2002) that occurred on 29th July 1947 in the northern part of Arunachal Pradesh closely associated with the MCT. The epicenter is located at 28.50N: 94.00E (see Nandy and Dasgupta, 1991 and Dasgupta et al, 2000). The epicentral tract was almost un-inhabited at that point of time and the present author is not aware of any macroseismic information for this event.

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* Both the notes are printed in a book entitled: China Burma India: Where I came in; Vol. II; Turner Publishing Company 1998; preview is available for selected portion through books.google.com. There are more entries in the book but was not available for free preview.

Meghalaya (India) - Bangladesh Border Earthquake of 1923

Possibly a similar ground situation was prevailing near the epicentral tract of the 9th September 1923 [8 days after the Great Kanto, Japan earthquake of 1st September] earthquake in southern Meghalaya. No published damage report for this event is available with the author. The epicenter of this earthquake is usually placed at 25.25N: 91.00E within the Dauki Fault zone. A revised epicenter is given as 24.94N: 90.32E with magnitude Ms 7.1 and focal depth of 35 km (Endgahl and Villasenor, 2002). This brings the earthquake epicenter closer to the town of Mymensingh south of the Dauki Fault. It is however somewhat odd to shift the epicenter to 25.50N: 91.50E right within the Shillong Plateau and yet refer the location as 'Mymensingh' (Ambraseys and Douglas, 2004); nevertheless this earthquake is possibly linked with activity of the Dauki Fault.

Srimangal (Bangladesh) Earthquake of 1918

This large event popularly known as the Srimangal earthquake of 8th July 1918 was studied by GSI and published (Staurt, 1919, 1926). The epicenter of the earthquake was given as 24.25N: 91.70E with a focal depth of 14 km. Isoseismal map was prepared following the Oldham scale. Epicentral parameters for this earthquake as recalculated (Endgahl and Villasenor, 2002) are; 24.81N: 90.72E (thus shifting about 110 km to the west by 55 km to the north), Mw 7.5 and focal depth 15 km. In our previous work (see Nandy and Dasgupta, 1991 and Dasgupta et al, 2000) the epicentral location was considered as 24.50N: 91.00E as per NEIC/ IMD catalogue. The isoseismal map has been modified (Ambraseys and Douglas, 2004) based on MSK scale and epicentral parameters suggested are; 26.50N: 92.00E (in the Brahmaputra valley!) and Mw 7.1. It is likely to be a misprint and must be rectified. Whatever may be the numerical location the earthquake has occurred in the Sylhet planes (Surma valley) and while spatially it is related to the Sylhet fault, in the regional framework could be linked with the Indo-Burmese convergence tectonics (see also Mukhopadhyay and Dasgupta, 1988).

Dhubri Earthquake of 1930

West of the Shillong Plateau bodering the Garo hills is located the Dhubri earthquake of 3rd July 1930. A comprehensive account for this earthquake was published by GSI. Based on field evidence Gee (1934) estimated epicentral location at 25.95N: 90.00E. A refined epicenter was given as 25.64N: 90.25E with magnitude Ms 7.1 and a focal depth of 35 km (Endgahl and Villasenor, 2002). Similar parameters were derived by Ambraseys and Douglas (2004) with epicenter at 25.80N: 90.20E and magnitude Mw 7.09. These authors also revised the isoseismal map based on MSK scale from the original map of GSI drawn following the Oldham Scale. Gee (1934) states; It appears that the Assam plateau topography originated in late Tertiary to sub-recent times as of result of earth- movements—sharp flexures accompanied by faulting along its southern and western extremities. With the relative advance of the Himalayas towards the south...., lines of fracture were doubtless formed to the north of the present plateau….The low lying areas immediately to the north, west and south of the Garo hills and the Shillong plateau are, therefore, in all probability zones of structural weakness, liable for earth-movements. The epicenter of the Dhubri earthquake lies near the junction of the northern and western of these zones, while the epicenters of certain of the more severe aftershocks appear to have been located further up the Brahmaputra valley within the northern zone of instability. The statement clearly indicates existence of three fault system; the Dauki Fault at the southern end, the Dhubri or the Jamuna at the western margin and the Brahmaputra Fault (Murthy and Sastri, 1981; Dasgupta and Nandy, 1982) in the northern margin. Both the 1897 and the 1930 earthquakes locate almost along the same latitude (estimates vary between 25.50 and 26.00N) separated by 100-120 km; the 200 km long south dipping Brahmaputra Fault between Guwahati and Dhubri could be responsible for both the earthquakes. Additional deep subsurface probe is however necessary to map out this fault because of its implications for SHA.

Earthquake Geomorphology

After discussing the large and great earthquakes that occurred in different tectonic domains of NER, I would like to touch upon another aspect which is equally important so far as SHA is concerned. None of the earthquakes discussed above have known to produce co-seismic surface rupture which is commonly associated with many large earthquakes of the world; except the Chedrang fault and some other fault/ fracture mapped by Oldham (1899), but not considered to be primary rupture associated with the 1897 earthquake. There is a possibility that such surface signatures even if produced have escaped recognition due to geopolitical or climatic (thick vegetation) constraints. While discussing these issues, in one of his article Bilham (2004) states; Information available to Indian authors on the effects of the earthquake were confined largely to a narrow corridor of information along the Brahmaputra valley since access to Tibet, Burma, or the tribal regions south of the epicenter was unavailable. Regrettably geologists did not make a thorough search for surface faulting in the epicentral region and geodesy near the epicenter was virtually non-existent.

Whatever may be the reason, the fact remains that primary surface ruptures associated with great and large earthquakes was either not produced (see Seeber and Armbruster, 1981 on reasoning for not being produced) or not recognized and mapped. In NER as already mentioned there area two advancing deformation fronts, the Himalaya and the Indo-Burmese orogenic belts. Contemporary activity produces geomorphic signatures and the most recent ones are likely to be preserved along the foreland margins of deformation front. For the Himalayan domain in NER the segment includes the area from Sankosh River in the west to Dibang in the east skirting Bhutan, Arunachal and Assam to the Mismi foothills; southern margin of the Assam shelf bordering the Belt of Schuppen; and the margins of the Tripura fold belt in Sylhet and Commila Districts in Bangladesh, all dominated by Quaternary sediments. Tilting of strata, warping and folding with anomalous drainage are some of the indicators for deformation. Short-listing such areas does not however indicate that deformation is not taking place in the interiors but it is difficult to segregate from geomorphic evidence due to its rugged topography and high rate of erosion. In general long-term aseismic deformation is a continuous phenomena primarily through creep but there has to be locales of strain concentration due to crustal heterogeneity and variation in local stress azimuths. Continuous deformation through creep generates micro-earthquakes; whereas fault- locked segments due for large earthquakes through episodic stick-slip movement, manifests through generation of fault propagation or fault bend folds, a common feature in a compressive environment prevailing in both the mobile belts. In a continental compressive environment like that in the Himalaya, thrust fault scarp is the most direct geomorphic evidence for paleo-earthquakes.

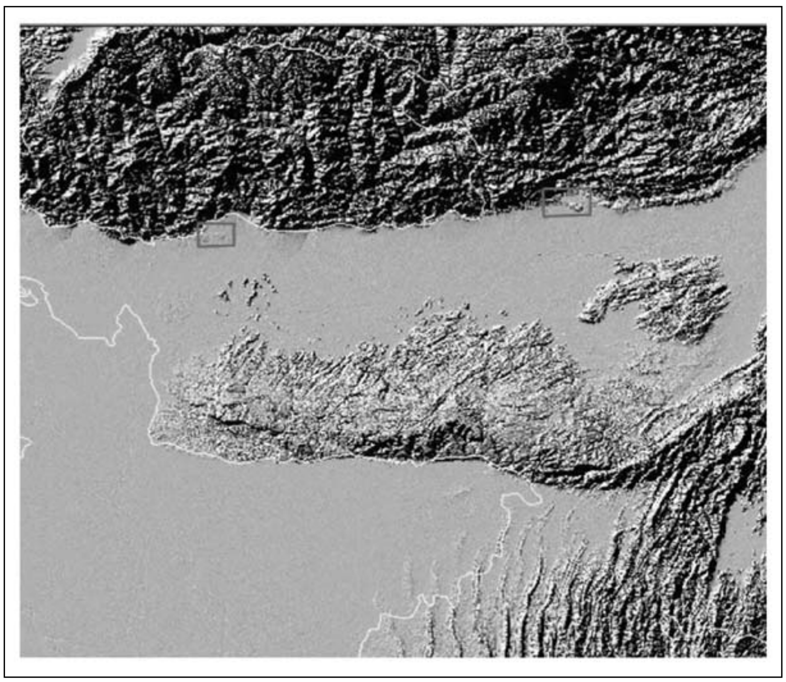

Figure2 : Frontal Himalaya sites in NER that show significant deformation features, ideal for paleo-earthquake studies.

Site specific study from eastern Himalaya and northeastern India is particularly lacking though some excellent work was carried out long back by Nakata (1972) from the West Bengal and Assam foothills. If we believe that large scale movements and shaping of the earths surface has been achieved primarily through successive great earthquakes throughout the geologic times, (including inter-seismic deformation) then for SHA there is no other alternative but to search deformed areas involving the late Pleistocene-Holocene strata either for the past earthquakes or for areas where earthquake is in the making. It is to be noted that as there has been few or no record of large earthquakes on many active faults and as records of surface fault lacking in many known earthquake belts, the task of identifying such deformed zones falls largely to geologist utilizing geologic-geomorphic attributes (and of late to geodesists through GPS data) rather than seismologist using historic or instrumental data.

Anomalous geomorphic features indicating neo-tectonic activity are abundant in NER from which reference will be made of three localities (Figures 2 and 5). An E-W trending ≈30 km long north facing fault scarp is exposed along the Bhutan- India (Assam State) border, within the Raidak- Ai interfluve, particularly between Pinkhua Khola in the west and Leu Pani in the east. A preliminary geomorphological map was prepared by Nakata (1972) based on which GSI revisited the area during 2005- 2010 for detail mapping and related studies. The prominent north facing scarp varies in height from around 25-30m in the Ultapani sector to as high a 55m+ in the Balu Khola to the west. The uplifted terrain is about 5 km in width that gently slopes to the south where there is another 8-10m high south facing scarp. The entire uplifted terrain is dissected by several antecedent streams; from east to west the different blocks as demarked by Nakata (1972) are: Ultapani, Saralbhanga, Lalbheti, Singimajli and Ripu (Figure 3). While the northern scarp indicates a south dipping back-thrust the south facing southern scarp is possibly the MFT dipping to the north. At the northeastern corner of the Lalbheti block in the Saralbhanga River section fault-propagation folds are clearly developed within a silty clay layer bounded by boulder beds; while in the northwestern corner freshly cut section by a branch of the Singimajli River exposes the shallow south dipping thrust passing between sub-vertical beds at the river bed level and sub-horizontal beds at a higher elevation. Anomalous east-west drainage following the base of the north facing scarp along with lacustrine clay deposits indicate damming of the south flowing rivers during episodic uplift through thrusting from early Holocene onwards. The geologic- geomorphic signatures dictates a wedge- thrust scenario (pers comm.; Roger Bilham and Doug Yule) south of the MBT and the Siwalik belt (both in Bhutan) and the structure in all probability display surface rupture of strong paleo-earthquake. The area between the south dipping thrust and the exposed Siwalik rocks is a ‘Dun valley’ in its formation stage.

GSI is carrying out GPS geodetic studies across the easternmost Ultapani structure. It may not be out of place to refer to similar north facing scarp in Thaljhora and at least two segments of south facing scarps in Chalsa and Matiali (north dipping MFT) all in West Bengal foot hills south of MBT (see also Nakata, 1972).

Another segment of the frontal belt that shows similar but matured ‘Dun valley’ (Figure 4) is in the Arunachal- Assam border along the Bhareli (Kameng) River. In this segment the river flows E-W between MFT – I bordering the foothills and the new MFT-II further south. The alluvium on the hanging wall side of MFT-II appears to be folded, uplifted and back- tilted. This frontal Himalayan segment is ideally suited for paleo-seismological studies though apparently there is no fault scarp which is the surface expression of recently ruptured fault plane.

The third locality (Figure 5) with anomalous geomorphic feature indicating recent activity is located at the juncture of the ENE- WSW Naga thrust and the NW-SE Mishmi Thrust; known as the Manabhum anticline. It is a WNW- ESE anticlinal ridge with fold axis sub-parallel to the regional trend of the Miju- Mishmi block, and plunges to the NW within the inter-fluve of the Lohit- Noa Dihing Rivers. The litho-assemblage of the Manabhum piedmont zone is a sand rock overlain by thick pebble-boulder bed and both the members are seen folded to form the anticlinal ridge. Away from the Manabhum ridge in the adjacent Noa- Dihing plains this boulder bed is sub-horizontal and overlain by younger fluvial sediments.

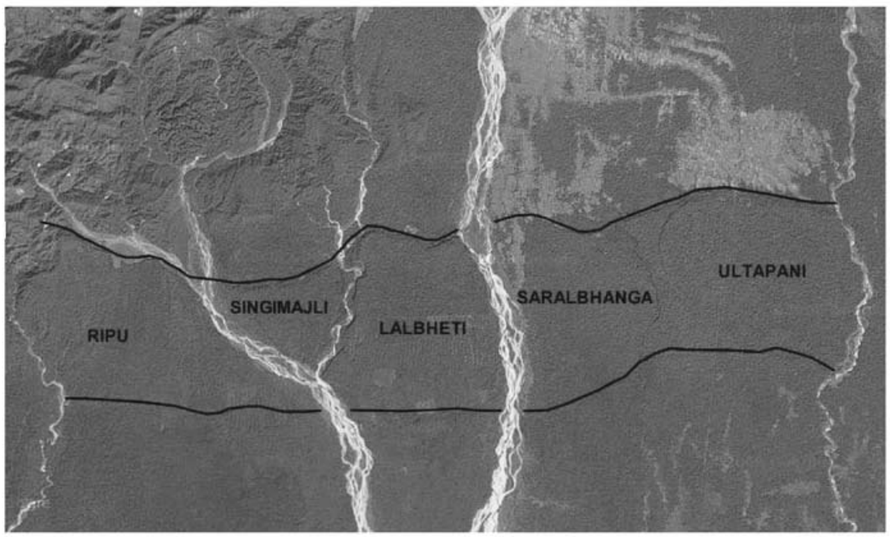

Figure3 : The Bhutan foothills structure; note lakes, marshy land and east-west drainage (formation of Dun type valley) along the base of the 30-50m high north facing scarp. The south facing southern scarp is much subdued. Both the scarps are of thrust-fault origin; the northern, south dipping back- thrust display signatures of latest activity.

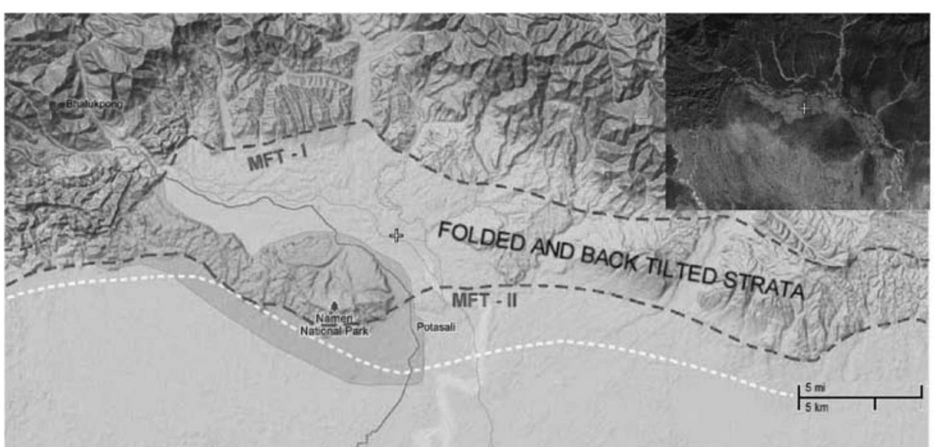

Figure 4: Active Structure in the Bhareli Dun, SE of Bhalukpong; note that the position of MFT- I and II is only approximate and requires field checking.

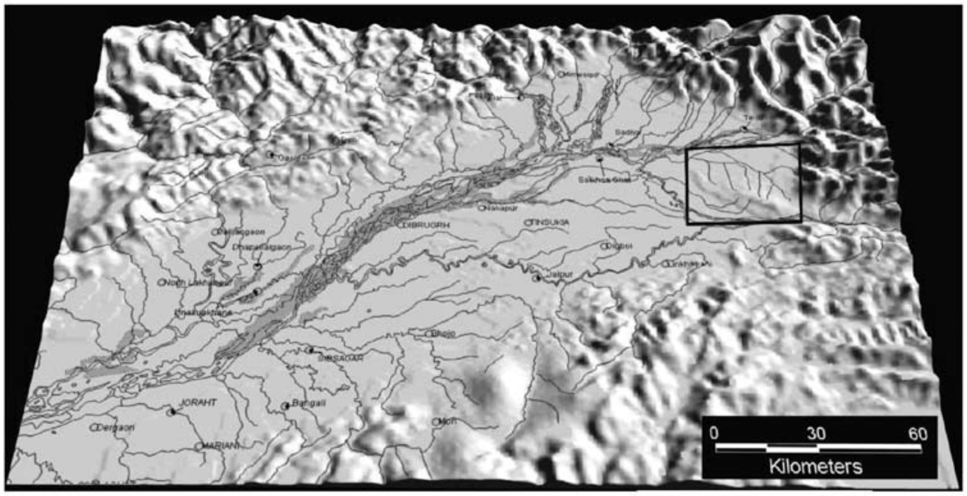

Figure 5 : The area within the black box is the Manabhum Anticline

The Manabhum structure (Figure 6) could be a ramp anticline or a fault-propagation fold over the tip of a buried thrust that dips towards ENE. The boulder bed is usually referred in geological literature as the Pleistocene boulder bed and its occurrence over finer sand rock indicate that these coarse sediments were brought down from the lifted hanging wall of the Mishmi hills during the penultimate thrusting episode. Contemporary folding activity in the area calls for geological, seismological and geodetic monitoring.

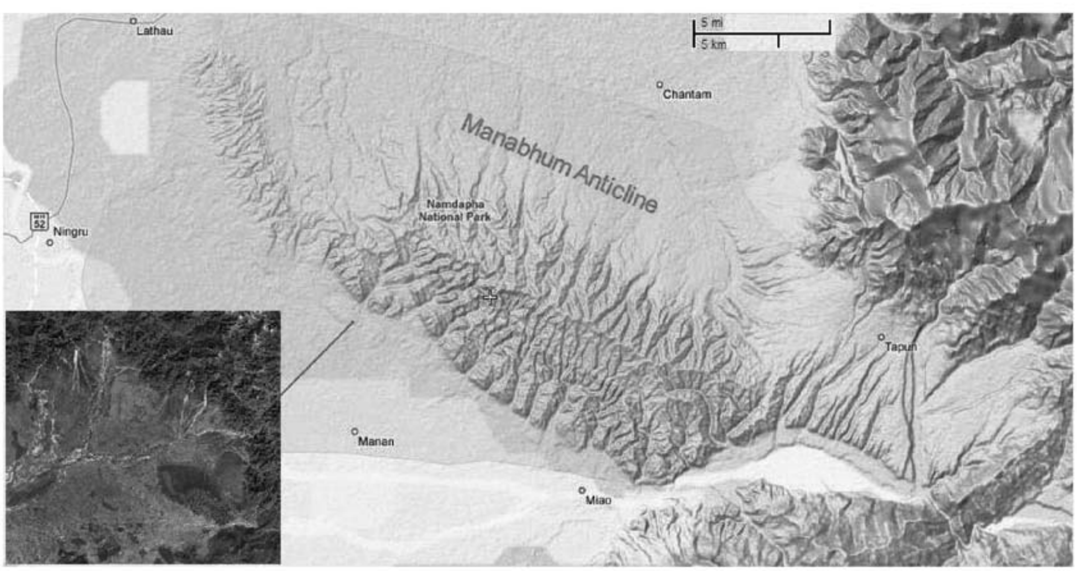

Figure 6: The Manabhum anticline, an active structure develops on the tip of a buried thrust.

Discussions

The present generation in NER is fortunate not to face the wrath of nature at least due to damaging earthquakes compared to its occurrence during the period from 1869 to 1950. Earth-scientist are however not complacent because geological, seismological and geodetic indicators of deformation are plenty. Lack of instrumentation and absence (or documentation) of surface rupture associated with the eight large earthquakes discussed has certainly constrained to decipher the nature of fault and associated slip for these events particularly in the Shillong plateau and surrounding areas. The fault activation scenario models, as discussed in the first part of this document, deserves more ground data primarily sub-surface up to crustal depths to characterize the faults be it Dauki, Oldham or Brahmaputra, Jamuna (Dhubri) and Kopili. One can wait till repeat earthquakes occur in these segments to collect various data, information through modern day instrumentation and concepts. This will be nature's own experiment. On the other hand earth-scientists can design their experiments similar in lines to International deep profiling of Tibet and Himalaya (INDEPTH) [a multinational venture with participation of several institutes of USA, Germany, China and Nepal]. Two N-S profiles across the Meghalaya plateau from Mymensingh- Sylhet plains in Bangladesh to Bhutan- Arunachal foothills and one E-W profile along the Meghalaya plateau covering the Garo-Rajmahal gap in west to Kopili gap in the east. These profiles should bring out and characterize the faults which are most wanted to direct SHA in this part of NER.

The geomorphic structures discussed are certainly related to long-term deformation on MFT and deserves detail study. While the young fault scarp developed in the Ultapani- Lalbhita area dictates for multiple morphogenic earthquakes, additional field data are required for the other segments to narrow down deformation spectrum. Surface geological and geodetic survey in actively deforming segments of the frontal belt involving neo-tectonic and paleoseismic approach would contribute to our understanding on the capabilities of active faults in the Himalaya-Mishmi- Belt of Schuppen segments.

Acknowledgement

The imageries used are from Google Earth, Wikimapia and other internet sources. Basab Mukhopadhyay, GSI is acknowledged for his support in annotating the illustrations and also for his constructive inputs in finalizing the paper.

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Three - Dimensional Tomography of Northeast India and Indo - Burma Region and its implications for Earthquake Risks

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Abstract : *In the present study, high resolution 3-D Primary wave seismic velocity (Vp) tomography has been carried out in the northeast and Indo-Burma region using a high quality of seismic phase data from the region, which reveals that a thick pile of the Bengal sediments and magmatic front arc are associated with conspicuously low-Vp up to a depth of about 20-km beyond the Dauki fault, while the Shillong Plateau and Indo-Burma arc is associated with high-Vp at shallower crust, indicating compact and competent crystalline rocks beneath the region. Occurrence of shallower earthquakes within the thick sediments beneath the Bay of Bengal may be hindered due to high ductility of the deposited thicker sediments, while genesis of plate boundary earthquakes in and around Indo-Burma region is corroborative with high-Vp anomalies. It is inferred from this piece of research that a thick-pile of ductile sediments of Bengal Fan can act as a safety blanket to coastal cities of both India and Bangladesh during sub-oceanic earthquakes of focal depth greater and equal to 20 km because of high attenuating and absorbing behavior of sediments. The inference drawn from this study may be used to assess the nature and extent of earthquake risks in the subduction zones and in areas of thick piled sediments under analogous geotectonic settings where collisional - subduction prevails.*

Keywords: *Earthquake Risks; Northeast India Region, Sediments, 3-D Seismic Tomography*

Introduction

The current tectonic activity in Asia is often cited as the consequence of continental collision, in progress, between India and Eurasia (Dewey and Bird, 1970; Molnar et al., 1973). The Indian and the Southeast Asian plates are separated by the wedged shaped Burma platelet (Curray et al., 1979) since the early Miocene. Further convergence since late Miocene has obducted the accretionary prism onto the Indian continental margin and has formed the Indo-Burma ranges (Figure 1a-b).

The tectonic evolution of Indo-Burma region is a product of the oblique convergence between the Indian and Southeast Asian plates in which the Burma platelet may be compressed northward (Curray, 1988). Only a few limited studies have attempted to determine the 2-D velocity structure of the crust and upper mantle in the region with a reasonable resolution of lateral heterogeneities (Sitaram et al., 1986; Gupta et al., 1990).

In the present study, detailed 3-D tomography method of Zhao et al. (1992) is applied to high resolution P-wave arrival time data to unravel the tectonic intricacies of northeast Indian and Indo-Burma region with special emphasis of delineating and detecting structural heterogeneities beneath the Shillong Plateau, Indo-Burma Ranges, magmatic fronts and of Bengal Fan sediments. Such endeavor may help ascertain what could be the plausible reason for non occurrence of moderate to strong earthquakes beneath the Bengal fan. This study also attempted to estimate plausible thickness of the Bengal Fan and its bearing on nature and extent of seismogenesis and degree of earthquake hazards. Estimate made by this study is also compared with other geophysical results to arrive at a plausible interpretation of the tomographic results to understand how image of sediments of Bengal Fan is resolvable using 3-D seismic tomography.

Geotectonic settings

The northeast region is one of the most tectonically complicated regimes among the entire Southeast Asia. The entire area is active since the Mesozoic to Tertiary times. The eastern part of the northeast India is formed by Naga - Lushai Hills. To the south of the Shillong Plateau

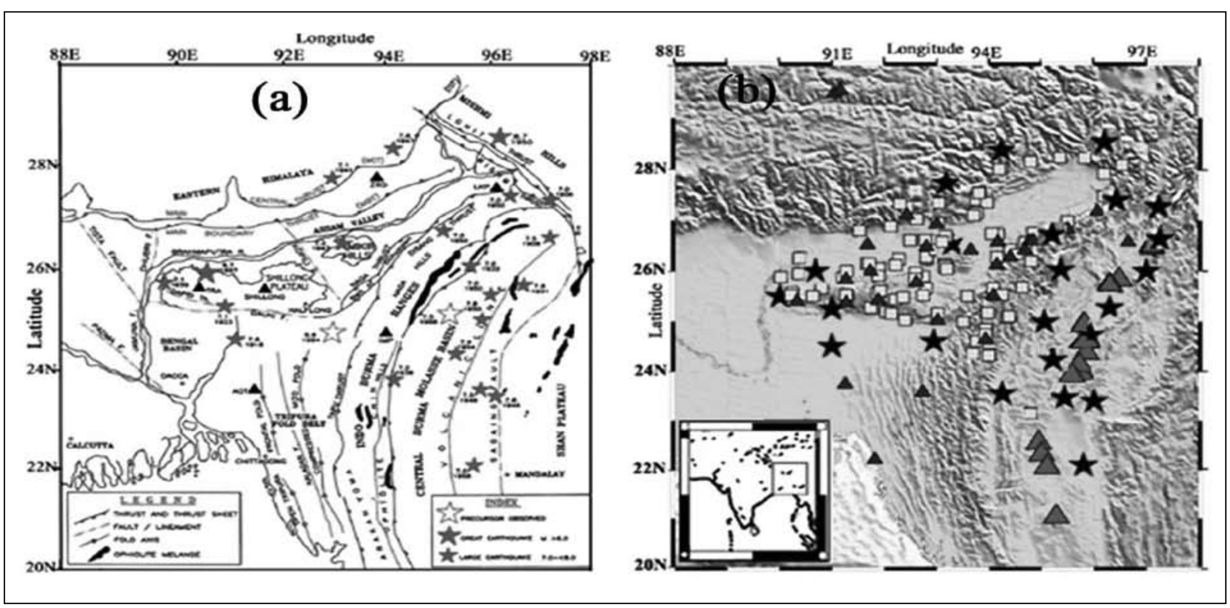

Figure 1: (a) Map showing topographic view of northeast India and Indo-Burma region. The black stars denote the great historic earthquakes (M > 6. 0). (b) Tectonic setting of northeast India and Indo-Burma region and surroundings (after Evans, 1964; Krishna, 1960). Stars denote big historic earthquakes. Black triangles denote some important locations of places.

there is the Bengal Basin separated by an east-west trending set of faults known as Dauki fault (Figure 1). The vertical movements have also played their part in the deposition of large thicknesses of sediments belonging to the Irrawady system of Burma and Bengal basin in India (Evans, 1964). In the south, Bengal basin is open to the Bay of Bengal (Figure 1b). The Mikir Massif is believed to be a fragmented portion of the Shillong Plateau and parted with a set of faults called Kopili fault (Evan, 1964; Nandy, 1976). The upper Assam Valley bounded on the southwest by the Mikir Hills and the Shillong Plateau (Figure 1b).

Geological, geophysical morphological trends and seismicity of Indo-Burma region (20-260N, 92-960E) suggest active subduction. This area is a transition zone between the main Himalayan collision belt and the Indonesian arc where the Indian plate is currently subducting under Asia. The Indo-Burman ranges extend from Arakan - Yoma upto Mishimi thrust belts and bulk of the ranges consist of Cretaceous to upper Eocene shales and sandstones which are considered to have undergone a major phase folding during Oligocene and Miocene (Mitchell and McKerrow, 1975).

The Bengal and Nicobar Fans were, for the first time, delineated and named by Curray and Moore (1971). Among these, the Bengal Fan covers the floor of all of the Bay of Bengal from the continental margins of India and Bangladesh to the filled Sunda Trench off Myanmar and the Andaman Islands, and along the west side of the Ninetyeast Ridge (Figure 2).The Bengal Fan is the largest and prodigious submarine fan in the world, with a length of about 3000 km, a width of about 1000 km with varying thicknesses (Curray et al., 2002). It has been formed as a direct result of the India – Asia collision and uplift of the Himalayas and the Tibetan Plateau. The northeastern edges of the fans have been subducted, and some of the Tertiary turbidites cropping out in the Indo-Burman Ranges of Myanmar, the Andaman and Nicobar Islands, and in the outerarc ridge off Sumatra have been interpreted as old Bengal and Nicobar Fan sediments (Figure 2). It is currently supplied mainly by the confluent Ganges and Brahmaputra Rivers with smaller contributions of sediment from several other large rivers in Bangladesh and India. A series of studies on the Bengal Fan established seismic stratigarphy by two unconformities over the exposed and buried hills of folded sediments in the southern

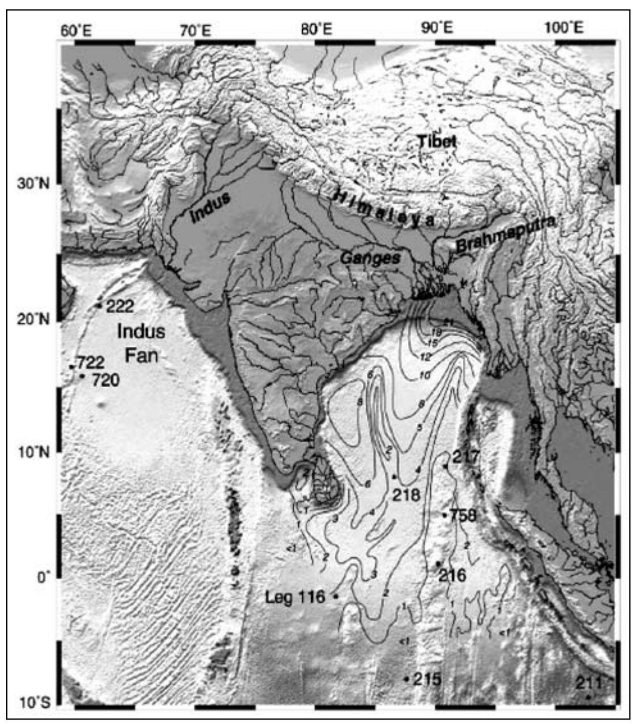

Figure 2:Geological map of northeast India and Indo-Burma region (after Krishna,1960).

part of the fan and over the Ninetyeast Ridge (Curray and Moore, 1971; Curray et al., 2002). They concluded that these two horizons are regional and used them to subdivide the sedimentary section into three parts in the Bay of Bengal. The ages of these unconformities were tentatively determined to be uppermost Miocene and upper Paleocene to middle Eocene (Curray and Moore, 1971; Moore et al., 1974; Curray et al., 2002). These studies revealed that the upper Miocene unconformity is the time of onset of the diffuse plate edge or intraplate deformation in the southern or lower fan. The lower Eocene uniformity, a hiatus which increases in duration down the fan, is postulated to be the time of first deposition of the fan, starting at the base of the Bangladesh slope shortly after the initial India – Asia collision. It is, however, the interpretation and significance of the older unconformity and the time of initiation of Bengal Fan deposition and progradation remain still very controversial.

Data and Method

In this work we selected arrival time data from two groups of shallow to intermediate-depth local earthquakes recorded by two different seismic networks (Figure 1a). One group of earthquakes consists of about 900 shallow and intermediate-depth local earthquakes recorded during 1984 - 2000 by 110 temporary and permanent seismic stations of India (Figure 3). The other group of earthquakes consists of 150 shallow to intermediate-depth earthquakes that occurred from 1964 to 2000 and were recorded by 25 seismic stations, which are reported to the International Seismological Center (ISC) Bulletins (Figure 3). Earthquakes were selected to keep a uniform distribution of hypocenters in the study region. These two groups of earthquakes are merged together for a better imaging of the study region. As a result, 4705 P- and 3301 S- wave arrival times from the 1180 earthquakes are selected (Figure 3). Accuracy of the arrival-time pickings is estimated to be about 0.1 – 0.15 s for the P arrivals and 0.1 - 0.3 s for the S arrivals (Mishra, 2004).

To analyze the arrival time data, we have applied the versatile version of 3-D tomographic method of Zhao et al. (1992), which was used by Mishra (2004). Although the conceptual approach of this method parallels that of Aki and Lee (1976), it has several additional features, which has found successful applicability in the diverse geotectonic settings in the world (Mishra, 2004).

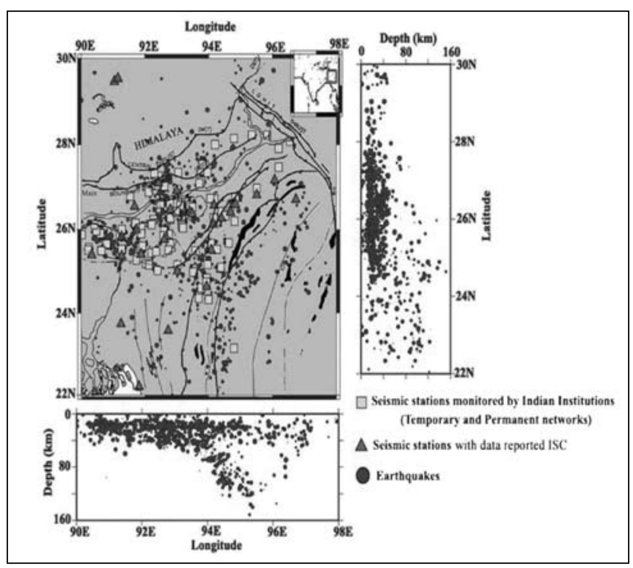

Figure 3: Map showing the plan and cross-sectional views of earthquakes used in this study.

Taking into account the distribution of

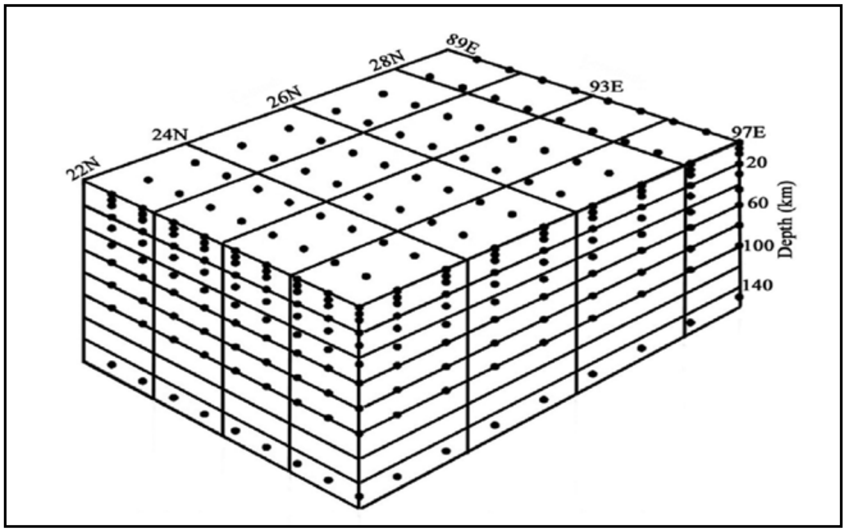

Figure 4: 3-D view of grid-net with horizontal and vertical spacing of 90 km and 5-20 km respectively. Dark dots denote grid nodes.

seismic stations and earthquakes, we set up 3-D grid nodes with a grid spacing of 90 km in horizontal direction and 5-30 km in depth (Figure 4). Based on integrated geo-scientific results, a crustal model is taken as the starting 1-D velocity model having the Conrad and Moho discontinuities at depths of 20.5 and 41.5 km, respectively.

The accuracy of the epicenter location and focal depth is generally better than 3 and 5 km, respectively. Detailed 3-D grid nodes is set up outside the study area for enhancing the spatial distribution of ray density by introducing several sets of ray paths, traversing for given set of station and earthquakes. Estimates of 3-D P-wave velocity structure are made only for inside portion of the study area that exhibits resolvable seismic structure.

Results and Resolution

Figures 5 - 6 show P-wave distributions in plan-views at different depth layers for the crust and upper mantle along with some past damaging earthquakes (Figure 2). Figure 7 shows the images in the vertical cross-sections along different profiles as shown in the inset map. Our results reveal strong Vp variations of over 5% in the study region. Strong structural heterogeneities in the crust and upper mantle reflect the complex geotectonic setting of northeast India and Indo-Burma ranges. In the upper crust, velocity variations are prevalent across the major faults and lineaments as shown in Figure 1. The Shillong Plateau, Mikir Hills, Assam Valley, Naga thrust belt, Belt of Schuppen, Haflong thrust sheet, the central Burma Molasse basin, Bengal basin, and the juxtaposition of the Disang thrust and the Mishmi Thrust are associated with low P-velocity (low-V) anomalies at shallow depth (0 - 10 km) (Figure 5a-b). High velocity (high-V) anomalies at shallow depth range appear at some localized zones, including the Dapsi fault in south, extending to the Shillong

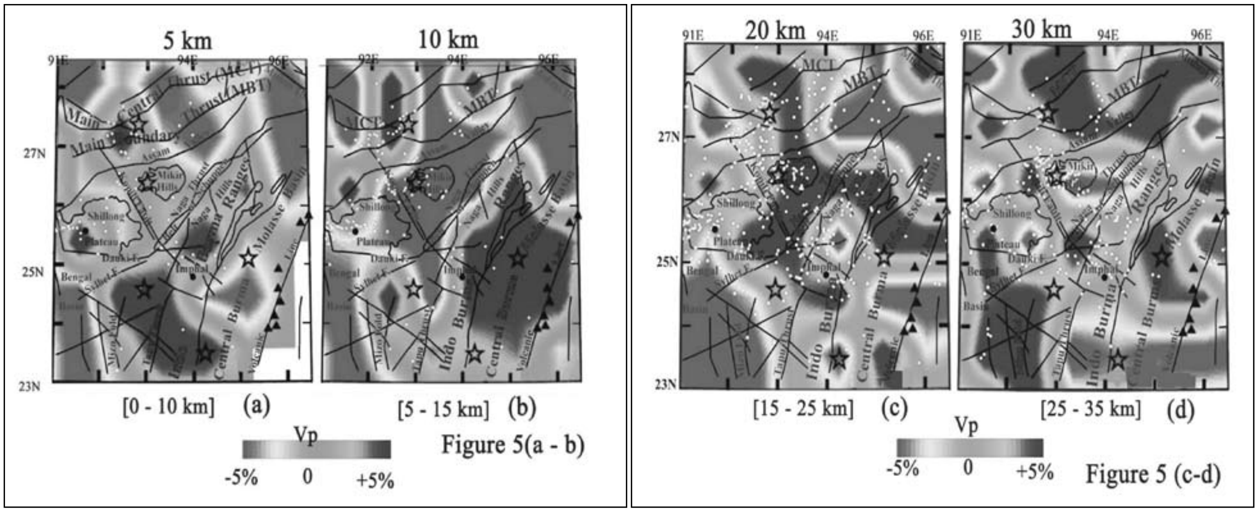

Figure 5: Distribution of Vp perturbations at different depths. The depth of each layer isshown at the bottom of images. The depth range of earthquakes (white circles) are shown at the top of each map. The stars and black triangles denote the past damaging earthquakes and Quaternary volcanoes, respectively. The thick lines denote faults and lineaments as shown in Figure 1. The big and small closed zones denote the Shillong Plateau and the Mikir Hills, respectively. The perturbation scale is shown right to the images.

Plateau. High-V is also imaged at shallow depth over the Mizo fold belt, the Tapu thrust belt, and the Naga Hills located in between MCT and MBT. The high–V observed across the Chin Hills in the western part of the Indo-Burma ranges. The Bengal basin in south to the Shillong Plateau is filled with thick sedimentary materials and the basin is imaged prominently by low velocity anomalies that extend down to 20 km depth (Figure 5c-d).

The resolution is generally high in the central part of the study area where alternate positive and negative patterns are well recovered. It is especially good for the mesh layer at 45 km depth where rays of Pn waves from crustal earthquakes intersect. The resolution toward the Burma plate in the subduction zone (25.40 -27.20N; 94.20 - 96.10E) is found to be good at deeper layers (60 - 80 km). The resolution of the assimilated Vp structure in and around the Bengal Fan and Mizo fold belt is found be very good at most of depth layers because of better criss-crosses of the seismic rays emanating from a set of source and arriving to various recorders.

Interpretation and Discussion

Complex geotectonics of northeast India, Indo-Burma region, and Bay of Bengal south of the Shillong Plateau may have contributed significantly to changes in structural heterogeneities of seismogenic faults and lineaments, which in turn may dictate the trend of seismicity and seismogenic strength at all depth ranges beneath the region. The pattern of Vp anomalies changes with depth, which shows a good correlation with collision and subduction tectonics of the region. The obtained tomographic results at deeper layers that clearly demonstrate the under thrusting of the Indian plate beneath the Burmese arc (high-V), volcanic activity of the Cenozoic volcanoes in the Burmese arc and thick sediment piles in Bengal basin (low-V) (Figures 5 -7). Our low-V zones in various parts of northeast Indian region may be attributed to sediments present beneath the major tectonic units at varying depth layers (Figures 5 – 7). Studies on geological structure and stratigraphy of the Indo-Burman ranges further support our interpretation that underthrusting of sediment and oceanic crust of the subducting Indian plates may have brought major phase folding during Oligocene and Miocene (Mitchell and McKerrow, 1975).

From 1897 to 2008, 18 large earthquakes (M ≥ 7.0) including the two great earthquakes (M > 8.0), occurred in this region (Figure 1), which caused a large-scale damage to the densely inhabited areas of the northeast India. The activity in the Tripura area, on the other hand, may be related to the plate-boundary activity (Kayal, 1998). A damaging earthquake (Mw 5.8) [known as the Cachar earthquake] occurred in 1984 at a depth of 32 km in the Tripura area (Mishra, 2004), which is located in a zone characterized by high-V in our tomographic results (Figures 6-7), and it supports the suggestion of Kayal (1998) that this earthquake might have been occurred at the plate-boundary where the Indian plate meets the Burma arc (Figures 6 - 7). Our results demonstrate that earthquakes occur in higher velocity zones within the Burma plate (Figure 7b-c). The causative zone is named as inland Burmese seismic slab by Mukhopadhyay and Dasgupta (1988). The inland seismicity is closest to the Benioff zone and visible below the Chindwin forearc basin.

It is worth to mention that none of such large earthquake of magnitude (≥ 7.5) so far occurred at shallow depth (≤ 20 km) beneath the Bay of Bengal. However, the 1918 Srimangal (Assam) earthquake (M 7.6) had occurred at unknown depth in the Bay of Bengal (24.50N; 910E) that resulted in a considerable damage to property and person (Gutenberg and Richter, 1954). We surmised that more damage could have resulted if it had struck to a layer having no thick-pile of ductile sediments. The present study suggests that the 1918 big earthquake (M 7.6) might have occurred at underlying Indian lithosphere beneath the overlying thick sediments of Bengal basin (Figures 2, 7). Non-occurrence of such large earthquakes within the Bengal Fan marked with low-V anomalies (Figures 5 – 7) may be attributed to the ductility of the sediments that hinders brittle failure and negates the possibility of seismogenesis in the ductile zone. The low seismic activity in the Bay of Bengal / Bengal basin has been interpreted due to a locked portion of the Indian plate below this basin, whereas a moderate activity can be observed in Tripura area (Kayal, 1998; Mishra, 2004). The present study infers that the seismic ativity in the Bengal basin may be related to an intraplate activity below 20 km. Based on above discussion high resolution 3-D tomographic images assimilated in the present study suggest an alternate interpretation for the low seismicity at shallow depth layers in the Bay of Bengal having thicker Bengal Fan; as the ductility of deeper sediments (> 10 km) of the Bengal Fan might contribute to low or virtually negligible seismicity in the Bengal Basin (Figure 7).

The thick pile of ductile sediments of Bengal Fan in the Bay of Bengal clearly imaged as low -V in the present study (Figure 7d) that may play a safe role by reducing degree of earthquake hazards during earthquakes because of its very high attenuating power to attenuate a majority of released seismic energy during major earthquakes. The interpretation of high attenuation is based on the fact that low-Vp has high attenuation and reverse is also true (Salah and Zhao, 2003; Mishra et al., 2005). In addition to that a part of seismic energy released during an earthquake may get absorbed and radiated in the ductile sedimentary layers of the Bengal Fan, which may contribute significantly in reducing the nature and extent of geo-hazards due to earthquakes. Thus a thick-pile of ductile sediments of Bengal Fan can act as a safety blanket to coastal cities of both India and Bangladesh during sub-oceanic earthquake. On other hand, site response study in micro-scale grid revealed that presence of loose and unconsolidated sediments at sub-surface may get amplified when seismic wave pass through it (Hough, 2000; Chowdhuri et al., 2008). In such circumstances structures built over thick pile of sediments may be raged to ground, enhancing the damage pattern. Contrary to this, thick pile (≈20 km) of ductile sediments beneath the Bay of Bengal is very much apt to hinder seismogenesis within it. As mentioned above seismic shaking on the ground may not be vibrant beneath the thick pile of ductile sediments in Bay of Bengal as the ductile sediments are capable to absorb and attenuate seismic energy, which may reduce the earthquake hazard by reducing effects of strong shaking and tsunamis. It is, however possible to amplify the sea tide due to seismic wave amplification within the sediments on the sea bed. However, more detailed future study using multidisplinary tools of geosciences (e.g., multi-channel results from seismic refraction, reflection methods coupled with detailed 3-D passive source tomography and gravity results) are needed to understand the geodynamical property of the Bengal Fan in relation to its depositional history and sub-oceanic earthquake genesis in the Bay of Bengal. In this context, a detailed study on seismic profiling using multi-channel method can provide deep insight into depositional history of sedimentary layers and their vulnerability to strong shaking and tsunamis in the Bay of Bengal. Alternate interpretation is that the thick pile of the Bengal sediments (> 20 km) may contribute significantly to major load along with an overthrust load of westward moving Indo-Burma ranges over the Indian lithosphere, which may amplify the stresses already acting on the Indian plate due to load of the Himalaya and making the region seismically more vulnerable (Bilham et al., 2001).

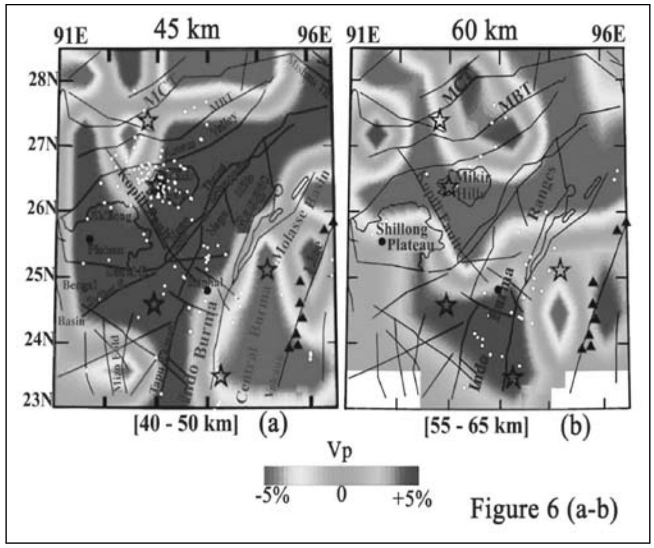

Figure 6 : Same as that of Figure 5 but at four different depth layers (45 km, 60 km). The depth range of seismicity are shown at the top of each map. The symbols correspond to the same as that in Figure 5. The perturbation scale is shown right to the images. Stars denote the past damaging earthquakes.

Hydrocarbon exploration on and offshore from southeastern Bangladesh (Kingston, 1984) shows total sediment thicknesses calculated from gravity to be greater than 20 km, apparently with the Eocene and Oligocene Disang Series of deep water shales and turbidites overlying oceanic crust (Curray, 2000). These are in turn overlain by Neogene prograding deposits of the Bengal Delta, of the Ganges, Brahmputra (Jamuna), Meghna, and their ancestral rivers, showing low-V anomalies in the assimilated 3-D structures (Figures 5 – 7). Some of this rock has been mildly metamorphosed and uplifted into the accretionary prism in the Indo-Burma Ranges associated with intermediate to high-V anomalies as shown in Figure 7(a - c). Some sparsely fossiliferous flysch units correlated with Disang series (Bender, 1983; Schwenk et al., 2005) are associated with low-V anomalies in the assimilated structures for Vp (Figures 5 – 7).

Analyses of seismic refraction and reflection profile by Moore et al. (1974), and Curray et al. (1982) suggested a total sedimentary section of over 16 km beneath the Bangladesh shelf. More recently, however, reinterpretation of data (Brune et al., 1993; Curray, 1994) suggest that the unit beneath the 16 km boundary is of high density, high velocity metasediment rather than oceanic layer 2, and that the total metamorphosed plus unmetamorphosed sedimentary section exceeds 22 km, which is very much corroborative with the present 3-D seismic imaging of different layers that show strong velocity signatures beyond 20 km depth (Figure 7d). Surface wave dispersion study by Singh (1992) revealed that sedimentary thickness in the Bengal Fan varied from 5.5 km to 12 km. Deep sediments in the Bay of Bengal belonging to the Irrawady system of Burma (≈ 3km thick) and Bengal basin in Indian part (≈ 13 km thick) estimated by gravity method (Krishnan, 1960; Verma et al., 1976), while estimates of sedimentary thickness made in this study is very much corroborative with the recent estimate of the sediments made by mass accumulation rate theory (Metivier et al., 1999) in which thickness varies from 12 km to 22 km. The blanketing effect of sediments, with consequent temperature rise, has brought about differentiation of basalt, with increase in crustal thickness (Brune and Singh, 1986). On the other hand extrapolation of temperature and pressure conditions to these depths (16 – 22 km) suggests greenschist facies, bottoming in amphibolite facies, while extrapolation of the horizon interpreted to be the Paleocene – Eocene unconformity to the 16 km boundary divides the section into a pre-Eocene, pre-collision metasedimentary section, overlain by Post-Paleocene fan sediments and sedimentary rocks (Curray, 2000), which are supported by the present 3-D tomographic study by showing low-Vp anomalous zones. Thus the present estimates of sedimentary thickness of the Bengal Fan and velocity signatures at various crustal layers are consistent with recent geological and geophysical studies and interpretations.

The coexistence of eastward subduction of Indian plate and volcanic activity through mid-Miocene to Quaternary period interpreted by Satyabala (2003) and Dasgupta et al. (2003) are well reflected in the present study. In the upper crust, the low-V zones are visible prominently along the Dudhnoi and Chedrang faults, Barapani shear zone, Kopilli lineament, Mikir Hills, Assam Valley, Naga thrust fault and the Belt of Schuppen at a depth of 10 km (Figure 5), where shallow crustal earthquakes (5 - 15km) occurred. These low-V zones, however, disappear at a depth of 20 km, and a new low-V zone is visible near the seismogenic Imphal lineaments in the Naga Hills, which is guarded prominently by high-V zones from all directions in the Indo-Burma ranges (Figure 5). This observation suggests the fault zones at depth and lateral variation in velocity structure. The low-Vp at shallow depth may correspond to surface geological features or sedimentary materials or the faults associated with trapped fluids or loose pelgic sediments due to episodic tectonic upheavals in the region, while high-V anomalies at shallow depth layers, possibly indicate the presence of dense crystalline rocks under compressive stress that are the source areas for seismic activity. The Central Burma Molasse Basin shows a prominent low-V at shallow depth (5 km), but the anomaly disappears at deeper layers.

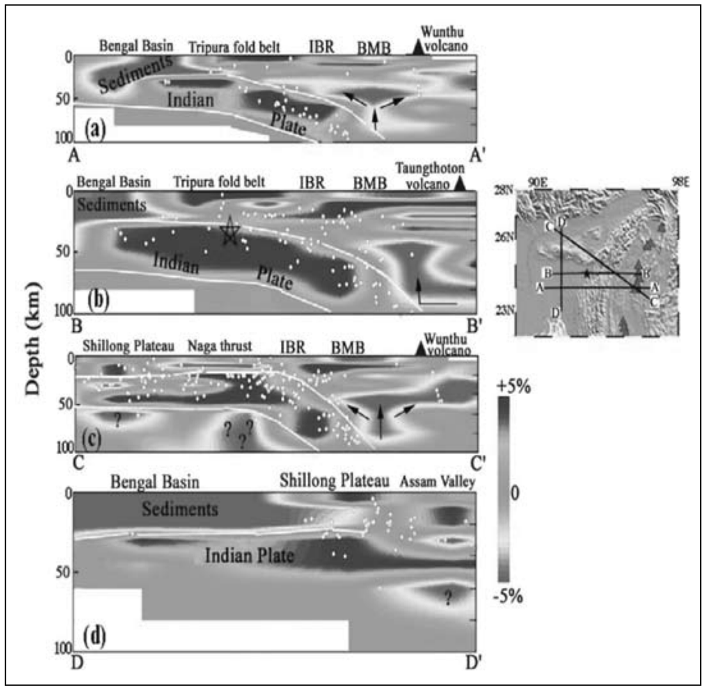

Figure 7: Cross-sectional Vp images along different locations shown in the insert mapat the bottom of images. Small white circles denote earthquakes within 30-km width along the respective cross-sectional line. The black triangles and a star denote Quaternary volcanoes of Burmese plate and the recent damaging 1984 Cachar earthquake (M 5. 8), respectively. The perturbation scale is shown to the right of the images.

In cross-sectional images the pattern of the low-V anomaly beneath the volcanic front is clearly reflected (Figure 7). Some crustal earthquakes, however, may occur in the volcanic region due to crustal weakening caused by active volcanoes and arc magma resulting from the convective circulation process in the mantle wedge and dehydration reactions in the subducting slab (Zhao et al., 2002). It may be mentioned that no volcanic activity has been observed in the Burmese mountains during historic times (Wadia, 1957), though one volcanic island with historical volcanic activity lies on the southward extension of the Burmese mountains (Fitch, 1970).

Seismogenesis has strong bearing on structural heterogeneities dictated by plate subduction, lithospheric structures, nature and extent of sedimentary layers, which can be studies in detailed by deploying multi-disciplinary tools of geosciences. A detailed study using 3-D attenuation in future may provide comprehensive information on nature and extent of attenuative behavior of the sediments of the Bengal Fan. It is, therefore necessary to use a large quantity of local and regional travel time data for imaging dipper subducted slab and entire Bay of Bengal Fan to unravel the status of the thick pile of the ductile sediments on seismogenesis to understand the pattern of geo-hazard due to sub-oceanic earthquakes

Concluding Remarks

The Northeast India region, including Indo-Burma Range and the Bengal Fan is one of the few geologically and seismotectonically intricate subjects of research in the world, where intermediate focus earthquakes occur. The region is apt for generating moderate to strong magnitude earthquakes and hence it is susceptible to earthquake hazards, depending upon the nature and extent of structural heterogeneities beneath the earthquake source zone. The present 3-D tomographic study demonstrates that there exist a significant lateral as well as depth variation in velocity structure. Existence of the eastward subduction of the Indian plate beneath the Burmese arc are associated with high-V, the Cenozoic volcanic front beneath the Burmese arc imaged by low-V), and thick ductile sediments in the central Burma Molasse (≈ 5km) and Bengal Fan (≈ 20 km) are conspicuously associated with low-V anomalies. The thick pile of ductile sediments of Bengal Fan in the Bay of Bengal clearly imaged as low-V zones in the present study, where none of earthquakes occurred, which may play a safe role during earthquakes if they occur below the ductile sediments because of its very high attenuating power to attenuate a majority of released seismic energy during major earthquakes. It is inferred from this piece of research that a thick-pile of ductile sediments of Bengal Fan can act as a safety blanket to coastal cities of both India and Bangladesh during sub-oceanic earthquakes. However, more detailed future study using multidisplinary tools of geosciences (e.g., multi-channel results from seismic refraction, reflection methods coupled with detailed 3-D passive source tomography and gravity results) are needed to understand the geodynamical property of the Bengal Fan in relation to its depositional history and sub-oceanic earthquake genesis in the Bay of Bengal. A detailed study using 3-D attenuation in future may provide comprehensive information on nature and extent of attenuative behavior of the sediments of the Bengal Fan. The information may also prove valuable for the hazard mitigation of earthquakes and volcanoes in intercontinental and coastal regions of analogous geotectonic settings elsewhere in the world.

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Active Fault Zones Mapping Using Geophysical Data in Parts of Shillong Plateau

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Abstract : *The Shillong plateau signifies the intense tectonic processes that the region has experienced during the Tertiary Indo-Tibetan and Indo-Burman collisions. An attempt has been made in this paper to take advantages of different geophysical studies such as Magnetotelluric, Microseismic (MEQ) and radon emanation to understand and map the active fault zones. The Magnetotelluric survey was conducted along a profile of Guwahati-Shillong–Dawki to locate the deeper crustal structures. The micro-seismic data were obtained along a network of stations. The network was utilized to monitor MEQ events during 1999-2000. Epicenter map prepared indicate sparse seismic activity over the Shillong plateau. Epicenter alignment shows definite pattern of the activity disposition indicating the active fault zones. The low b-value indicates asperity and that the 'stress' is being built-up. The deeper active crustal structures occur as a group of related fault traces and create relatively permeable and porous zones that serves as conduits to the surface for radon produced at depth. Along the few zones delineated using the magnetotelluric and microearthquake study the radon monitoring was done and the sites where radon signals are present were demarcated, using the LR 115 detectors and continuous radon monitoring using the Barasol mc 2 is carried out and are delineated as active fault zones or sensitive sites.*

Keywords: *Active fault zones, Magnetotelluric technique, Microearthquakes, Radon monitoring, Shillong Plateau, Dawki Thrust.*

Introduction

The Shillong plateau is a composite cratonic block and occupies a crucial position between the Himalayan arc to the north and the Indo Burmese arc to the east. The Shillong Plateau, known to be the detached portion of the Indian shield comprises of the Archean to Proterozoic Gneisses with acid and basic intrusive, covered by Quartzites, Grits and Slates, known as the Shillong group of rocks, acutely folded and steeply dipping with an overturned fringe of Mesozoic and tertiary sediments including Sylhet traps (Mesozoic flood basalts) (Fig.-10.1). The southern margin of the plateau is demarcated by a sharp fracture zone known as the Dawki fault extending from Jadukata river (West Khasi hills district, Meghalaya) to Haflong (North Cachar hills district, Assam) in the east where it passes into the Haflong thrust (Bilham and England, 2001, Nandy, 2001).

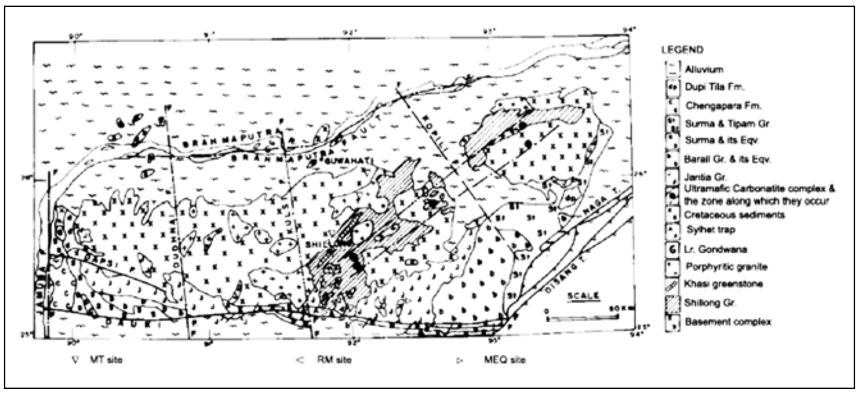

Fig- 10.1: Geological Map of the Shillong Plateau (after Nandy, D. R., 2001)
1- Basement Complex; 2- Shillong Group; 3- Khasi Greenstone; 4- Porphyritic Granite; 5- Lower Gondwana; 6- Sylhet Trap; 7- Cretaceous Sediments; 8- Ultarmafic Carbonatite complex; 9- Jaintia Group; 10- Barail Group and its equivalent; 11- Surma and its equivalent; 12- Surma and Tipam Group; 13- Chengapara Formation; 14- Dupi Tila Formation; 15- Alluvium.

Shillong plateau had experienced two major earthquakes of magnitude ≥ 7.0 during the last 100 years. There are a number of N-S, NNE-SSW and NE-SW trending morphotectonic lineaments and fracture zones. The area is tectonically very active due to the collision of the Indian plate with Tibetan landmass in the north and ongoing subduction process between the Indian plate and the Shan-Tenasserim block in the east.

The positive gravity anomaly over the Shillong plateau is related to the presence of higher density crustal material at shallow depths, which is arching the plateau. The steep gravity gradient across the southern margin of the Shillong plateau significantly marks the contact of the thick pile of sediments in the Bengal basin and the Sylhet traps along the Dawki fault (Fig-10.2). Gravity & Magnetic surveys have identified a few criss-cross features in the close proximity of the surface trace of the Dawki fault. These may be inferred as structurally disturbed zones or the active fault zones (Verma and Mukhopadhaya, 1977).

Magnetotelluric Technique

Magnetotellurics (MT) is a natural-source, electromagnetic geophysical method of imaging structures below the earth's surface and is used for deciphering the crustal configuration including

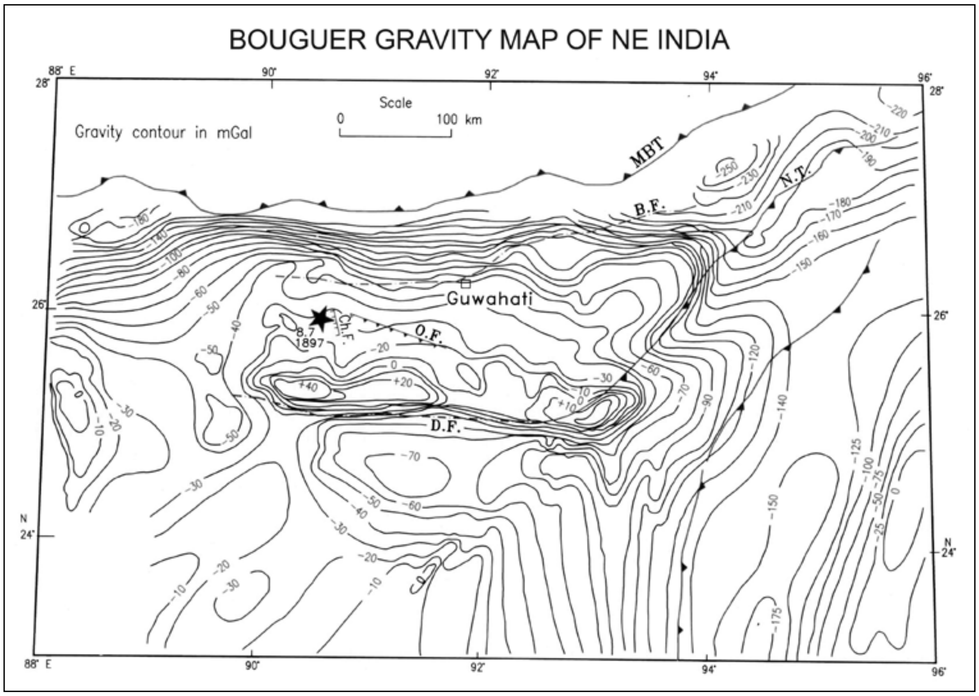

Fig-10.2: Gravity Anomaly Map of NE India (after Verma and Mukhopadhaya 1977)

the discontinuities, ruptures and faults. As we all know that the natural variations in the earth's magnetic field induce electric currents (or telluric currents) beneath the earth's surface with variable distribution. The two horizontal components of the electric field (along the magnetic N-S and E-W, denoted as Ex and Ey, respectively) and three orthogonal components of the magnetic field (along magnetic N-S, E-W and vertical, denoted as Hx, Hy and Hz, respectively) are measured synchronously in the form of time series (Fig-10.3).. With this information, the impedance tensor (Z) is computed and hence the apparent resistivity of the structure is obtained after GB decomposition, modeling and inversion. The results are important indicator of the conductivity for distinguishing crustal configuration and hence the structure including active fault zones lying underneath. Because of the skin effect phenomenon, the higher frequencies give information on the shallow Earth, whereas deeper information is provided by the low-frequency ranges. The impedance is usually represented as apparent resistivity and phase as a function of frequency. Electrical conductivity is an important physical parameter of the rocks and sediments. Imaging of the Earth's subsurface conductivity has become an important step in identifying rock types, and understanding tectonic processes and geologic structures.

Broadband Magnetotelluric data were collected from 11 stations along Byrnihat - Dawki profile using the Phoenix MTU-5A system. The data were collected with a frequency band

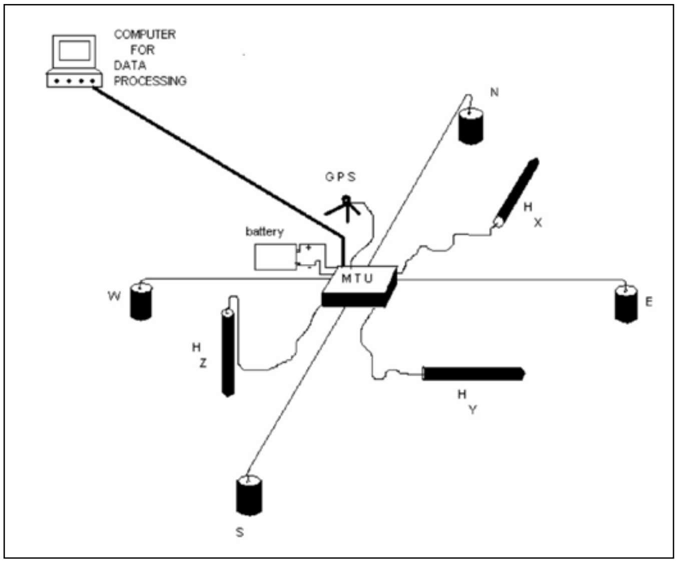

Fig 10. 3: Field Layout of a Magnetotelluric setup.

of 300-0.0001Hz. The Byrnihat - Dawki (N-S) profile covers nearly 100 km as liner distance (Fig.- 10.4).

The interspacing between consecutive stations is approximately 5 km. However, it was difficult to maintain the same gap due to rugged topography with a dense forest cover, the site interval over Shillong Plateau was largely governed by the availability of suitable sites (Table- 10.1). The impedance tensors were obtained by using a combination of the fast Fourier transforms and cascade

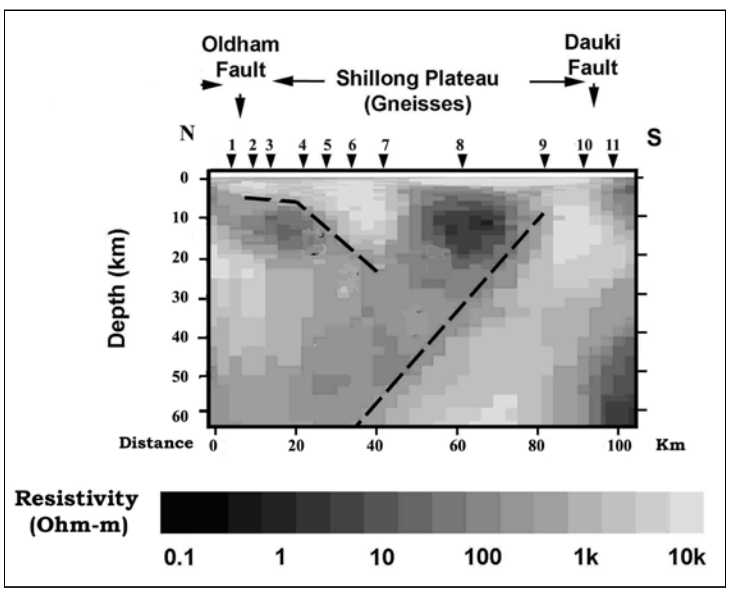

Fig-10. 4: Crustal configuration along the Guwahati – Shillong – Dawki Profile

Table-10.1: Location and Geological Details of MEQ Stations.

Station	Code	Latitude N	Longitude E	Exposed geological formation
Mawtawar	MAW	25o 36' 50"	91o 55' 00"	Weathered Quartzite
Muktapur	MKP	25o 09' 30"	92o 07' 30"	Rocks belonging to Sylhet Traps
Shangpung	SPG	25o 28' 45"	92o 21' 15"	Exposed Quartzite
Umkiang	UMK	25o 01' 29"	92o 23' 30"	Compact Phyllite

decimation procedure (Wight and Bostick 1980). The impedance tensors were decomposed in order to obtain the regional strike angles free from near surface inhomogeneous using the Groom and Bailey (1989) procedure. The impedance tensors at all frequencies, at each site were rotated, at intervals of 5 degrees, to obtain the twist and shear for each rotation. Thus the frequency invariant values of the shear and twist were determined and, hence, also the range of the strike angles over which these parameters were reasonably stable. The shear and twist thus obtained at each site were fixed and the unconstrained strike angles were obtained at each frequency for all the sites.

Microearthquake Data Acquisition and Analysis

Portable MEQ recorders (RS-2) Kinemetric made and short period vertical seismometers (SS-1) were deployed. The Pg arrivals were read with an accuracy of + 0.1 second and Sg with 0.25 to 0.5 seconds. The earthquake parameters like origin time, coordinates of epicentres, hypocentral depths were determined using Hypo 71 program (Lee and Lahr 1975). In the study area, the sites were selected where deeper structures were expected to cut across the geomorphologic features on the basis of variation in the lithology and structures as deciphered using Magnetotelluric technique and microearthquake data.

The seismometers at each location were kept in contact with the exposed bedrock to obtain good recordings and to reduce significant noise levels. A network of micro earthquake (MEQ) stations at Mawtawar, Muktapur, Shangpung and Umkiang was utilized to monitor MEQ events during 1999-2000, a total of 119 MEQ events were recorded. Out of these, 35 events occurred in the close proximity of the network (Table10.2). Events occurred in the close proximity of the network were spatially located. RMS errors of the location are within 0.5 sec, depth and epicentre error with in + 5 Km are plotted

Radon Monitoring Procedure and Interpretations

The different rock types and their structural dispositions were studied and recorded in the field (Table- 10.3). The detector LR-115 Type II Cellulose Nitrate pelliculable films (manufactured by Kodak Patthe, France) of size 2.5cm X 2.5 cm having upper threshold energy of 4.8 MeV were placed to record the concentration of radon. The film was placed in an inverted cup in PVC pipe. The detector assembly was kept in a 1metre deep dry hole and was exposed for a period of about

Table-10. 2: MEQ data for the use of HYPO' 71 software

DATE(YMD)	ORIGIN (Time)	LAT N	LONG E	DEPTH (m)	MAG	RMS	ERH	ERZ
991215	22-47-08	25.39.06	91.30.51	17.87	3.69	0.23	-	-
991220	11-22-25.62	25.08.45	92.31.64	2.38	2.26	0.74	-	-
102	19-36-53.62	25.57.59	91.33.17	12.85	3.03	0.1	-	-
103	08-24-02.44	25.10.82	92.20.09	18.73	2.64	0.2	2	4.1
116	12-39-47.93	25.11.71	92.16.27	13.33	2.09	0.22	2.1	5.6
129	10-23-43.07	25.19.59	92.40.15	0.12	2.47	0.11	2.62	-
130	00-29-10.71	24.58.21	92.01.69	42.82	3.11	0.34	8.6	5.7
130	18-33-25.39	25.04.74	92.34.23	34.25	3.37	0.02	0.7	0.5
201	17-56-49.77	25.48.97	93.07.90	12.92	3.48	0.08	5.6	2
20203	14-09-48.65	25.06.97	92.10.48	19.61	2.67	0.24	6.2	3.3
205	21-19-51.34	25.27.56	92.18.22	10	3.99	0.32	-	-
205	23-30-13.27	25.30.54	91.39.99	18.24	2.88	0.14	-	-
212	14-24-32.76	25.23.67	92.49.35	19.89	2.56	0.99	-	-
223	07-09-10.40	25.05.52	92.30.05	28.21	3.12	0.14	2.5	2.8
225	17-58-27.76	25.53.30	91.33.97	7.68	2.75	0.2	4.5	2.6
229	18-13-52.66	25.55.71	93.01.66	22.86	3.74	0.73	-	-
309	01-27-53.11	25.50.72	92.52.28	20.39	2.99	0.59	-	-
310	18-04-06.62	25.09.26	92.06.08	23.05	3.61	0.09	1.6	1.4
319	14-10-08.31	25.15.10	92.14.12	27.32	2.44	27	5.4	8
321	12-06-15.60	25.02.34	92.10.52	38.89	2.33	0.15	2	1.7
324	15-10-47.79	25.21.97	93.03.00	11.02	2.82	0.13	2.4	1.7-
326	15-18-14.15	26.36.32	92.59.55	2.43	3.26	0.38	-	-
331	00-20-33.67	24.34.77	92.22.42	8.74	2.79	0.23	3.8	4.1
402	03-04-58.24	24.56.66	91.52.52	40.32	2.91	0.06	3	0.9
402	11-35-50.39	25.46.17	91.07.2	10.07	3.42	0.12	6.4	2.5
403	11-50-34.94	25.28.73	91.59.67	2.32	1.6	0.34	0.1	2.2
404	13-05-21.25	25.55.76	91.18.20	9.87	3.21	0.46	-	5
406	17-10-36.18	25.12.43	92.14.29	15.93	2.65	0.37	2.5	4.7

40 days. In order to analyse the seasonal variation of radon levels, the films were reloaded and reinstalled after two months at few sites. Chemical etching of the exposed films was done in 2.5 N NaOH at 55oC for 90 min in constant temperature etching unit so that the latent tracks be revealed. The track density was measured using the optical microscope at a magnification of 1000X with calibrated grided eyepiece (Table-10.3). The number of tracks is proportional to the number of target atoms, flux, the reaction cross section and the time of irradiation. The radon concentration was determined after appropriate calibration of the detectors. Finally, the results were analyzed to

identify variation in the lithology and structure (Table-10.3 and Fig.- 10.5). The concentration of radon (CR) in Bq.m-3 is determined from the track densities in etched LR-115 detector (T1) using following equation:

$$C_R = T_1 / K_R\, d, \tag{1}$$

where KR is the calibration factors for radon gas in the etched LR-115 detector and d is duration of exposure in days. The background levels as determined are subtracted from the concentration of radon to get the actual radon emanation from the deeper source.

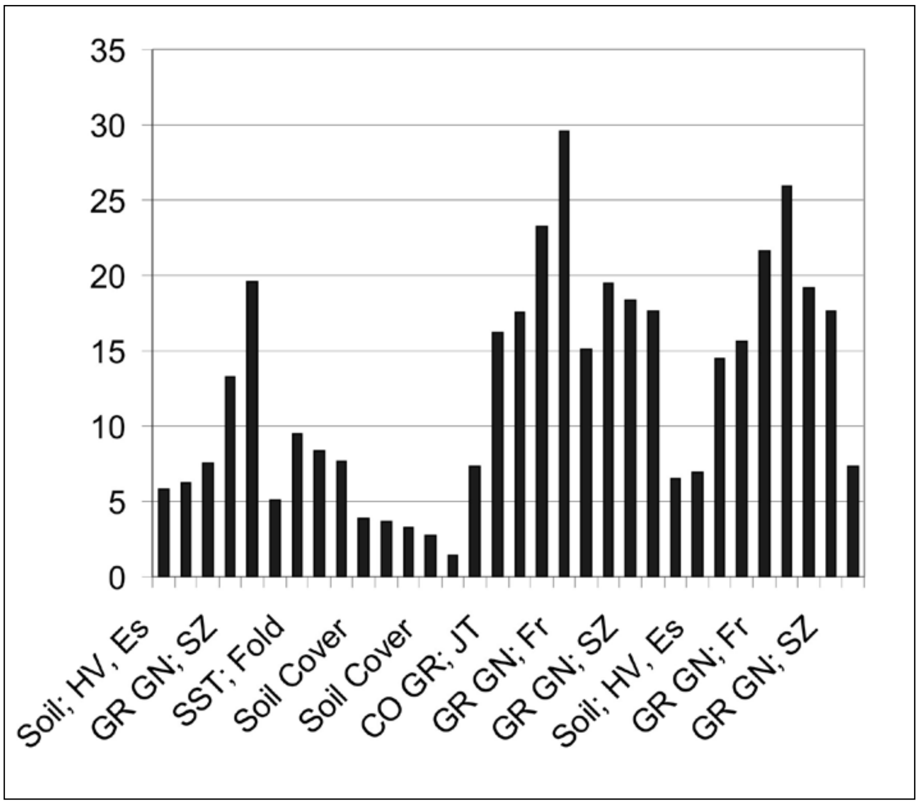

Fig-10.5: The diagram showing the relationship between the emanation rate of radon(Y axis) (Bq/m3) to the lithology and structures present (X axis)

Results and Discussion

(i) The Magnetotelluric data indicates the presence of Oldham fault towards the north of the Shillong Plateau and the Dawki thrust at the southern margin, which also explains the sharp change in the gravity data (Fig- 10.4). The Shillong Plateau which is considered to be the pop up structure represented by the sudden change of elevation along its borders is basically due to the presence of south dipping Oldham fault and north dipping Dawki fault. The MT data thus help us in demarcating the area where the deeper faults may crop out.

(ii) A clustering of MEQ events has been found along the Dawki Fault system with depths ranging from 0-40 km. Epicentral map prepared from these events indicates sparse seismic activity over the Shillong plateau area. The focal depth of the epicenters over the Shillong plateau area lies in between 4 to 30 km. Many events have been found at the intersection of the Dawki fault and the Halflong thrust thus showing that it is active.

Another evidence of active fault zone has been collected by using Gutenberg and Richter (1941) equation which establishes relationship between the cumulative number of earthquakes and its magnitudes. The 'b' value of the equation which shows regression coefficient, as moderate as 0.53 that is far lower than the normal (around 1.0). Thus, low value may indicate that strain is being build up in this part of the area for a possible major Earthquake occurrences in the near future

Epicentral Map

The epicentral map shows a sparse seismic activity. A small clustering of MEQ events align in the E-W direction has been found along the Dawki fault around Muktapur - Amlarem - Umkiang area. The maximum focal depth is around 40 kms. It indicates that most of the earthquakes occurred within 0-40 km at the near vertical Dawki fault (Fig-10.6) The FPS shows a NNE-SSW directed compressional stress. The focal depth of the events in the Shillong plateau area are confined to depth less than 30 km. A few epicenters on the northwestern part of Khasi hills were attributed to Kulsi fault. Many events are recorded in the proximity of the Dawki fault zone and at the junction where the Dawki fault meets the Halflong Thrust.

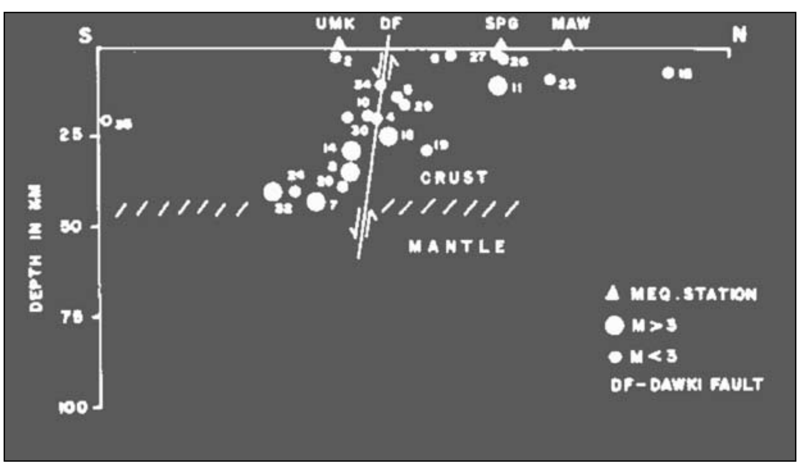

Fig- 10.6: Depth Section of the Earthquakes N-S depth section of the earthquakes (epicenters with in 20 km on both sides are considered)

At station K06, J02, J04, J05, J06, J08, J09, J10 and J11, the recorded radon concentration seems much higher (ranging from 15-30 KBq/m3) in a structurally complex zone of faulted and foliated granite gneiss, porphyritic coarse grained granite with joints, pegmatite veins and near hanging valley, whereas at other stations like K01, K02, K04, K05, K08, K09, K10, K11, J01, J12 and J14, the radon concentration is high (ranging from 5-15 KBq/m3). Such values are due to the presence of porous and permeable sandstone with fold structures and the soil or till with hanging valleys and fault escarpment. At remaining sites the radon concentration is recorded normal (ranging from 1 – 5 KBq/m3). The anomalous radon concentration is controlled by the presence of structural features including shear zones, fracture zones and highly permeable soils resulting from the weathering of granites and the lithological variation (Table -10.3). It has also been observed that the radon concentration is higher above the basement granite gneiss as compared to the granites and other flood plain or fan deposits including sandstone. Radon concentration is related to geological conditions and is high near the locations as deciphered are: Faults and shear zones – groundwater leaching or country rock, precipitation of radium daughters (less soluble minerals) in fracture zones, shear zone crushed rocks; Anticlines with tension fractures; Highly permeable soils; Pegmatite dikes.

Conclusions

The deeper and active crustal structures have been identified using the MT technique and Microearthquake studies. The Magnetotelluric and Microearthquake studies are used to delineate the active fault zones and monitoring of radon emanation method is used to understand and identify precisely the surface expression of such active fault zones and are mapped. The deeper active crustal structures occur as a group of related fault traces and create relatively permeable and porous zones that serves as conduits to the surface for radon produced at depth. The radon moves through the newly created planes of weakness, after radon recoil, and by diffusion and advection. The radon monitoring along such structures indicates the positive correlation. Hence, the area around Dawki – Pynursla seems to be active and indicates the presence of active fault zones. The continuous long term radon monitoring is to be made along the sensitive sites by using the BARASOL MC 2 for modeling the identification of active fault zones for seismic event forecasting.

Acknowledgement

We are grateful to Dr S. G. Gokarn, Indian Institute of Geomagnetism, Navi Mumbai for his generous help and suggestions.

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Site Response Estimation from H/V Ratio based on Ambient Noise Measurements of Shillong City

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Abstract: *H/V ratio technique is used to assess the site response through estimation of fundamental resonant frequency in Shillong city, capital of Meghalaya. In this regard ambient noise measurements are carried out at 70 sites in different parts of Shillong City. The minimum duration of noise recording is about one hour. It is observed that the fundamental resonant frequency for Shillong City emerges out to be in the range of 3 to 7 Hz. Variation in the resonant frequencies suggests heterogeneous lithological conditions of the region. Besides, a good correlation is found to exist between Geology of Shillong City and HVSR results, obtained in this study.*

Key words: *Ambient noise, H/V, site response, resonant frequency*

Introduction

It has been observed that the damage associated with the occurrence of earth tremors is the result , not only of magnitude of the earthquake of earth tremors and its epicentral distance , but also of local site effects which are essentially frequency dependent caused by topography and geology of the site. The reaction of the local geological conditions to the incoming seismic energy is known as the site response (Fernandez et al., 2000). For seismic hazard assessment, the site effect is typically represented by resonance frequency and the associated ground motion amplification. Several methods exist such as array data analysis, horizontal to vertical ratio HVNSR, site to reference spectral ratio with a view to estimating such parameters. Out of these, use of ambient vibration records for determination of fundamental resonant frequency has recently gained world-wide acceptance. It is well known that soil deposits amplify ground motion. The amount of amplification depends on several factors including layer thickness, degree of compaction and age (Siddiqqi et al., 2002). One of the many reasons for choosing ambient noise as widely accepted by several authors is that it allows the quick & reliable estimate of site characteristics of any type of area. Apart from being a cost effective measure, it reduces time compared to estimating site characteristics from earthquake which has always been a time consuming as well as expensive process so far as the maintenance of equipment & man power is concerned.

There are many instances of successful utilization of this H/V ratio estimate towards studying fundamental frequency from ambient vibrations in urban environments (Duval et al., 2001; Lebrun et al., 2001; Panou et al., 2005; Guegen et al., 2000; Lombardo et al., 2007; Garcia-Jerez et al., 2007, Mundepi et al., 2009 & many others). The proximity of fundamental frequency of a site to the existing man-made structures causes damage of the later owing to resonance effects. Therefore, investigation of each site condition is an important step towards earthquake hazard mitigation.

North East Region of India has been proclaimed as one of the most tectonically active region in the world. Two great earthquakes one in 1897 and the other in 1950 had already ripped past through this region. One of the most striking features of NER, India that most of its cities and densely populated settlements are located in valley, sedimentary basins or hills etc. In this study, we try to shed light upon the site characteristics of Shillong City in terms of resonant frequency, site amplification etc using H/V ratio methodology ((Nakamura's 1989; as modified by Bard, 1999).

Geology and Seismicity of Shillong

Shillong forms the type area of Shillong series of parametamorphites, which includes mostly quartzites and sandstones followed by schist, phyllites, slates etc. The base of Shillong series is marked by a conglomerate bed containing cobbles and boulders of earlier rocks, i.e., Archaean crystalline, which formed the basement over which the Shillong series of rocks were originally laid down as sedimentary deposits in Precambrian times, probably in shallow marine conditions. The rocks were intruded by epidiorite rocks, known as "Khasi Greenstone" as depicted in the Geological map of Shillong in Fig 1. The Khasi Greenstone is a group of basic intrusives in the form of linear to curvilinear occurring as concordant and discordant bodies within the Shillong group of Rocks and suffered metamorphism (Srinivasan et al., 1996). The rocks are widely weathered and the degree of weathering is found to be more in topographic depressions than in other areas. The metabasic rocks are more prone to weathering than the quartzite rocks. In low lying areas, valley fill sediments are also prominent. Numerous lineaments of varying magnitude and having major trends in E-SW, N-S and E-W directions (Chattopadhay and Hasmi, 1984) are found in the vicinity of Shillong City.

Shillong Plateau within which our study area falls is regarded as one of the most seismically active region in NER, India. It is separated out from the peninsular shield and moved to the east by about 300 km along the Dauki fault (Evans, 1964). The study area is juxtaposed between two active faults, i.e., Dhuburi fault and Oldham Fault (Oldham, 1899). It is surrounded by many small & large faults & lineaments. Towards the western part of Shillong, there exists the active Barapani

Shear Zone. It is one of the major thrust faults prevailing in this region. The complex geodynamics of Shillong Plateau resulted in the Great Assam earthquake of 1897. As reported by Bilham, this (MS=8.7) earthquake caused severe damage to the settlements of this area (Shillong city), causing causalities in a large dimension. Mention may be made about the significant earthquake of June 1, 1969 with a magnitude of 5.0 having an epicentral distance of 20km from Shillong (Gupta et al., 1980). According to Gupta, since 1970, there has been gradual decrease in P-wave velocity yielding a speculation that the region is experiencing a dilatancy stress precursory to a large earthquake (Semnov, 1969). According to Khatri, 1992; the Shillong Massif shows a pertinent seismic activity with an average of 10-15 small magnitude earthquakes per day. Over the past hundred years, there were instrumental records of 20 large earthquakes. With the advent of seismic networks set up by RRLJ Network, IMD, there has been a tremendous improvement in the micro tremor records. During the past recent months, there has been a contemporary rise in the no. of felt tremors whose epicenters lie within the vicinity of Shillong City. This populous city of Shillong is not far from the rupture area of the Great Earthquake of 1897(MS=8.7). The maximum magnitude for historical seismicity has been reported as 8.7 (The Great Shillong Earthquake) whilst for instrumentally recorded seismic activities, the maximum magnitude is 6.2. The moderate magnitude seismicity in the Shillong area is somewhat confined to Barapani Shear zone. In the context of this ongoing pattern of seismicity, the current study will be an initiative towards microzoning of this region.

Data acquisition and Processing

Ambient noise survey was made in 70 different sites of Shillong City encompassing major part of the city (Fig. 2). The area of observation was divided into 500 x 500 meshes. Since, Shillong is a well developed & populous city; hence there are certain constraints regarding noise recording in urban environments. To ensure reliable noise recording, we followed the guidelines proposed by Koller et al. (2004) in the framework of SESAME. Besides, quiet environment & good weather condition had been our prime requisite for executing this data acquisition process. The minimum duration of ambient noise recording was around one hour. During this survey, we used Teledyne Geotech-1s triaxial velocity sensors equipped with 24 bit Reftek 72A-08 digitizer. The data is digitized at 100 samples per second and recording time was maintained by Reftek GPS clock. The locations of the ambient noise sites were determined by the GPS.

Data from each site has been processed using LGIT Software i.e.; SESARRAY package. Since similar sensors are used for all the three components, therefore no instrumental correction has been applied. The processing schemes are listed below.

- Determination of stable windows in the 30-40s range , using an antitrigger with 1-s STA , a 30s –LTA and STA/LTA ratio threshold of 0.25 and 2.50 as minimum and maximum respectively.
- For each window, a 5 % cosine taper is applied on both sides of the window signal of the Vertical (V), North-South (NS) and East-West (EW) components.

- For each window, an FFT is applied to the signal of the three components to obtain the three spectral amplitudes, to which a Konno and Ohmachi smoothing factor(1998) is applied with a bandwidth of 40 and followed by an arithmetical average.
- Subsequently, spectral ratios (NS/V, EW/V), and average (NS, EW)/V are computed.

In order to ensure whether an H/V peak is of natural or anthropic origin, each H/V peak is tested by Randomdec method (Huang and Yeh, 1999; Dunand et al., 2002; Guillier et al, 2007). As observed, the origin of the H/V peak is ascertained to be of anthropic origin if the critical damping is found below 5%; otherwise it is considered to be generated by natural origin wherein we get a critical damping above 5%. The frequency, pertaining to the low damping, as affirmed by the Randomdec technique to be of industrial origin is not considered for further analysis and interpretation.

Results of Fundamental Frequencies estimated from H/V ratio

Following the guidelines of SESAME (2004) and after testing through the Randomdec Method, the H/V ratios were evaluated for the sites where ambient noise recordings were made. Two different ranges of frequencies are observed to exist from the H/V ratio estimates. The first category of frequency is found within the range of 1 to 2 Hz. Similarly, the other range of frequency is observed to be above 2 Hz, as displayed in Fig 3(a). The resonant frequencies which are in the higher category of frequency might be caused by the presence of hard soil strata. These contemplated results are in next observation where it is aimed at searching for correlation with local geology. It is observed in Fig 3. that the H/V curve corresponding to site no.30 exhibits sharp peaks as well as higher resonance frequency. Similarly, H/V ratio estimates are obtained for other sites.

Fig 3(b) portrays the contour distribution of resonant frequencies. So far as the low frequency peaks are concerned, which is also not so sharp, might be caused by surface layer having moderate impedance contrast with the underlying formations. It is observed that certain regions which are encompassed by higher frequencies from 5 to 7 Hz are covered by compact strata of rocks such as greenstones, quartzite as evidenced in the Geological map of Shillong. However certain sites in the heart of the Shillong City exhibit lower fundamental frequency in the range of 1 to 2 Hz. The sites having lower frequencies indicate that these sites are marked by the presence of weathered soil cover which are considered as one of low velocity zones when correlated with local geological condition.

Correlation with litholog

There are ensembles of litholog information at 14 sites of Shillong city. This litholog information is correlated in conformity with the location of neighboring ambient noise sites. In this case as an example, two profiles AB and CD are observed in Fig 2. Profile AB comprises of three boreholes.

Similarly, profile CD which has a trending in SNE direction encompasses six boreholes. On the basis of borehole profile data, we made an attempt to reconstruct geological cross-section across the observed profiles as displayed in Fig 4. Towards the objective of correlating resonance frequencies estimated from H/V ratio, a plot of frequencies versus reconstructed geological cross-section is made.

As shown in Fig 4, we divide the resonance frequencies into three classes. The first range is from 1 to 3.5 Hz; the second between 3.5 to 5.5 Hz & the third one starts from 5.5 to 7.5 Hz or above. As we move along profile AB, i.e.; northwestern side to the east-southern part, interestingly we observe a transition from higher frequency to lower frequency. In the higher frequency portion, it is obtained as an average resonance frequency of 5 Hz. As observed by many researchers (Guegen et al, 2000; Siddiqui et al., 2002, Souriau et al., 2007), the existence of higher frequencies may be attributed to the presence of hard rock strata. This supposition holds good in this case excluding some variation in frequencies revealed by sites 29 & 28. Site no. 4 & 5 showed higher resonant frequencies, consistent with the presence of more compact thick rock strata (sand rock; as evidenced from the reconstructed cross-section). Towards the eastern-southern edge of the AB profile, existence of lower frequency is prominent. Inspections at the reconstructed portion indicate that there exists a comparatively lower density clay stratum. Further in some cases it may be related to the degree of compactness of the strata.

On the contrary, a wide variability in resonance frequencies starting from west-southern part to north-southern region is contemplated in profile CD. Along profile CD, site no 69, 56 & 39 show a gradual shift to higher mode of fundamental frequencies. On the other hand site number 60, 61 & 62 reveals a declination to lower side of resonant frequencies. Perhaps, thickening of weathering layer can be another contributing factor. The good correlation between the HVSR results and litho-log of Shillong City complements our results. This work can be regarded as the initiative towards microzoning of this area which is to be supplemented by other geotechnical and geophysical studies in order to reveal the detailed pattern of site amplification in future.

Conclusion

From our study, the following inferences have been drawn.

(1) The fundamental resonance frequency for Shillong city is found within the range of 3 to 7 Hz.

(2) Major parts of the area shows an appreciably higher fundamental frequency which leads to the implication that there exist thicker strata of basement rocks underlying the surface layer yielding sharp peaks in the H/V ratio.

(3) Wide variation of resonance frequencies at short distances among recording sites indicate a lateral heterogeneity prevailing in soil layers of the region. Northwestern side to the east-southeastern part of the city shows an average resonance frequency of 5 Hz which is evident

from correlation of existing litholog information as well.

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Earthquake Hazard in the Northeast India – A Seismic Microzonation Approach with Typical Case Studies from Sikkim Himalaya and Guwahati City

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Abstract : *A comprehensive analytical as well as numerical treatment of seismological, geological, geomorphological and geotechnical concepts has been implemented through microzonation projects in the northeast Indian provinces of the Sikkim Himalaya and the Guwahati city, representing cases of contrasting geological backgrounds - hilly terrains and predominantly alluvial basin respectively. The estimated maximum earthquakes in the underlying seismic source zones, demarcated in the broad northeast Indian region, implicates scenario earthquakes of MW 8.3 and 8.7 to the respective study regions for deterministic seismic hazard assessments. The microzonation approach as undertaken in present analyses involves multi-criteria seismic hazard evaluation through thematic integration of contributing factors. The geomorphological themes for the Sikkim Himalaya include surface geology, soil cover, slope, rock outcrop and landslide integrated to achieve geological hazard distribution. Seismological themes, namely surface consistent peak ground acceleration and predominant frequency were, thereafter, integrated with the geological hazard distribution to obtain the seismic hazard microzonation map of the Sikkim Himalaya. On the other hand, the microzonation study of the Guwahati city accounts for eight themes - geological and geomorphological, basement or bed rock formations, landuse, landslide, factor of safety for soil stability, shear wave velocity, predominant frequency, and surface consistent peak ground acceleration. The five broad qualitative hazard classifications - 'Low', 'Moderate', 'High', 'Moderate High' and 'Very High' could be applied in both the cases, albeit different implications to peak ground acceleration variations. These developed hazard maps offer better representation of the local specific seismic hazard variation in the terrain.*

Keywords: *Seismic Microzonation, Maximum Earthquake, Guwahati City, Sikkim Himalaya, Peak Ground Acceleration*

Introduction

India stands highly vulnerable to the seismic hazards owing to burgeoning population and extensive developmental investments. In the past, the country has experienced several devastating earthquakes namely 1897 Shillong, 1905 Kangra, 1950 Assam and 1934 Bihar-Nepal earthquakes, 1993 Latur, 1997 Jabalpur, 1999 Chamoli, 2001 Bhuj, and 2005 Kashmir. At the regional level, hazard zonations of the country has been provided by BIS (2002) and the Global Seismic Hazard Assessment Program (GSHAP, Bhatia et al., 1999). The four zones demarcated by BIS namely Zone II, III, IV and V has been respectively assigned hazard factor of MSK intensity of VI (or less), VII, VIII and IX (or above) with the corresponding zone factors designated as 0.10g, 0.16g, 0.24g, and 0.36g respectively. However, it has been understood in recent times that the variation of seismic hazard could be large even at local levels implying a need to incorporate the site conditions such as site response, surface geology, geomorphology, soil, topography, etc along with geotechnical secondary hazard factors leading to seismic microzonation (Nath, 2005).

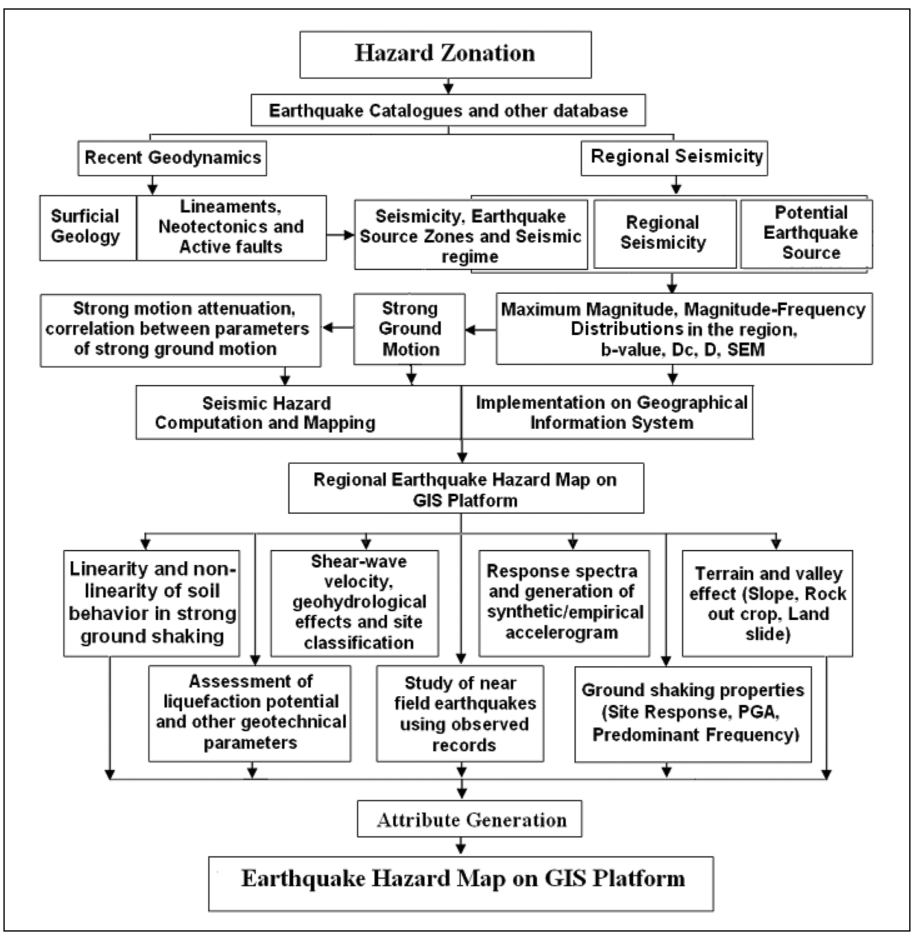


Figure 1: A seismic microzonation framework for earthquake hazard mapping.

The seismic microzonation is subdivision of a region into smaller zones that have relatively similar exposures to various earthquake effects. The underlying concept arises from the fact that the effects of surface geology on seismic motion could be considerably large. Several studies on devastating earthquakes have demonstrated a large concentration of damage in specific areas due to site-dependent factors related to surface geologic conditions and local soils altering seismic motions (Borcherdt, 1970; King and Tucker, 1984; Aki, 1988; Field et al., 1992; Nath et al., 2000; Nath et al., 2002). A framework for typical quasi-probabilistic/deterministic approach is depicted in Fig 1. It involves a large scale seismicity analysis for seismic source zone classification and estimation of maximum earthquake magnitude or maximum credible earthquake to be used as a scenario earthquake magnitude for seismic scenario generation. The various inputs include earthquake catalogues, information about lineaments, neo-tectonics and active faults, and geological and geotechnical aspects that can include: (a) bedrock topography, (b) subsoil profile, (c) soil site classification, (d) peak ground acceleration (PGA), (e) liquefaction potential mapping, (f) geomorphological characterization, and (g) probabilistic/deterministic seismic hazard scenario. The seismic microzonation is accordingly achieved through integration of the thematic layers pertaining to the various hazard components, following a multi-criteria evaluation technique such as Analytical Hierarchical Process (AHP, Saaty, 1980). The technique employs a hierarchal structure via pair-wise comparison based on forming judgments between two particular elements rather than attempting to prioritize an entire list of elements. A matrix of pair-wise comparison between the factors is thus built on a scale in a process of allocating weights in the participatory mode in which a group of decision makers may be encouraged to reach a consensus opinion about the relative importance of the factors. The various features within each theme are then assigned ranks or scores, normalized to ensure that no layer exerts an influence beyond its determined weight.

The Sikkim Himalaya comes under high seismic hazard zone designated as Zone IV, while the Guwahati city is placed within the highest level of seismic hazard – the Zone V according to seismic hazard zonation of India (BIS, 2002). GSHAP predicts high hazards in terms of PGA to the tune of 0.3 g (1g=980 gal) in the Sikkim region and as high as 0.35 g in the Guwahati region. Sikkim consists of the Himalayan hilly terrains; while on the other hand, the Guwahati city represents a case of well-formed basin with deep sediments and alluvial geology. The city had experienced damaging earthquake hazard from 1897 Great Shillong earthquake on the western frontier. Newly developed areas are rapidly emerging in these high earthquake prone regions towards developing its natural resources and improving the quality of life of the inhabitants. In the recent times, rapid growth in demographic distribution as well as expanding structural developments has led to huge implications on the vulnerability to earthquake hazards and the associated risk. Furthermore, the earthquake susceptibility is greatly enhanced due to the underlying complex tectonic and topographic features. The case studies as presented here formulate amalgamation of different perspectives of seismic scenario through the development of different thematic layers depicting spatial distribution of various contributing attributes, and integration thereof on a Geographical Information System (GIS) platform. In the present studies, the mapping and the vector union operations of the thematic layers has been achieved with the ArcGIS/ArcMap 9.1 software.

The Regional Seismicity

The high seismicity of the northeast Indian region has been attributed to a complex tectonic province displaying juxtaposition of the E-W trending Himalaya and the N-S trending Arakan Yoma belt. The major tectonic background includes the eastern Himalayan structures, the Mishmi massif, the Indo Myanmar arc, the Brahmaputra valley, and the Shillong plateau. The Himalayan structures mainly consists of the thrust planes namely the Main Central Thrust (MCT), Main Boundary thrust (MBT), Main Frontal Thrust (MFT), and their subsidiaries (Nandy, 2001). The movement along the Po Chu fault, in the northeastern part of the region, is believed to have caused the 1950 Great Assam Earthquake of MW 8.7 (Ben-Menahem, 1974, Thingbaijam et al., 2008). The Shillong plateau has been implicated with a pop-up tectonics associating the 1897 Great Earthquake of MW 8.1 (Bilham and England, 2001). The southern end of the Kopili fault is believed to have generated the 1869 Cachar earthquake of MW 7.4. The Indo-Myanmar arc, sidelined by Patkoi-Naga-Manipur-Chin hills, has been associated with 1988 Manipur Earthquake of MW 7.2. Overall, seismic activities in the region have been quite significant.

Thingbaijam et al. (2008) developed a consistent MW catalogue for the northeast Indian region, and carried out the subsequent seismicity analyses, leading to the demarcation of seismic source zones in the region. The catalogue derived from the International Seismological Center earthquake catalogue (ISC, 2007) and the Global Centroid Moment Tensor (GCMT) database covers a period of 1906-2006, and the region bounded within the latitude-longitude: 19ºN 85ºE and 32ºN 101ºE. The seismicity analysis in the region delivered the spatial distribution of seismicity parameters - b-value, and the correlation fractal dimension, DC. The seismicity patterns as quantified by the parameters in conjunction with the underlying tectonic network and the observed seismicity has been used to broadly classify four seismic source zones - Eastern Himalayan Zone (EHZ), Mishmi Block Zone (MBZ), Eastern Boundary Zone (EBZ) and Shillong Zone (SHZ) as depicted in Fig 2. The region exhibits assorted earthquake mechanisms - predominantly normal in EHZ, strike slip in MBZ and SHZ, and oblique reverse in EBZ. The SHZ has been associated with a popup tectonic model (Bilham and England, 2001). On the other hand, albeit EHZ exhibits normal to the north, the trend to the south especially on the MBT could be seen with strike-slip motions.

The assessment of mmax in the four seismic source zones of the northeast Indian region has been carried out by Thingbaijam and Nath (2008). A maximum likelihood method for mmax estimation referred to as Kijko-Sellevoll-Bayesian (K-S-B; Kijko 2004; Kijko and Graham, 1998) has been applied in each of the case. The technique employs a Bayesian based frequency magnitude

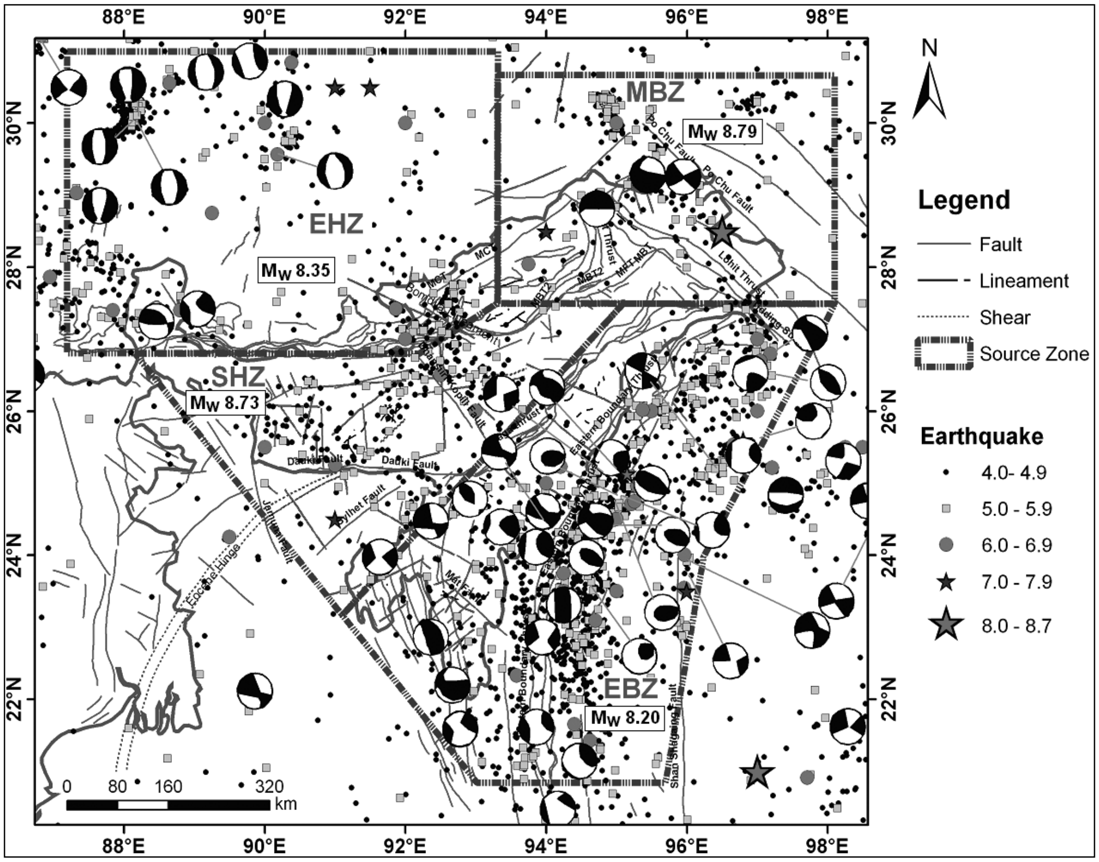


Figure 2: The four seismic source zones in the northeast Indian region.

distribution equation. The empirical magnitude distribution is implicated to be deviated moderately from the Gutenberg-Richter relation following an exponential tail of a Gamma function at the larger magnitudes. The aftershocks were removed from the sub-catalogues through the method employed by Knopoff et al. (1982) to create Poissonian event records. Each sub-catalogue has been segregated according to the temporal data completeness. The estimated b-value for the long term seismicity in the source zones corresponds to 1.05(± 0.06), 1.32 (± 1.36), 1.17 (± 0.04), and 1.00 (± 0.09) for EHZ, MBZ, EBZ, and SHZ respectively. EHZ, MBZ, EBZ and SHZ have been designated with mmax of MW 8.35 (±0.59), 8.79 (±0.31), 8.20 (±0.50) and 8.73 (±0.70) respectively. Accordingly, the scenario earthquake magnitude (SEM) for deterministic hazard analysis applicable to Sikkim Himalaya and Guwahati city respectively has been implicated to be MW 8.3 and MW 8.7 respectively. The former corresponds to EHZ and the later to SHZ. The Sikkim Himalaya falls in the province of EHZ while the Guwahati city is within SHZ. The great earthquakes of 1897 in the SHZ and 1950 in MBZ are far-field events for the Sikkim Himalaya considering the near-field effects from the hazard potential view of the eastern Himalayan zone. On other hand, the historical perspective of the earthquake hazard from 1897 Shillong earthquake, which occurred quite close to the Guwahati city as compared to the 1950 Assam earthquake, presents rather singular and highest hazard potential to the city.

Site Response Studies in Sikkim Himalaya and Guwahati city

Techniques used widely to quantify site response (SR) from strong motion data include the traditional spectral ratio and the generalized inversion approach (GINV, Boatwright et al., 1991). In case of weak motion data, a simple technique for estimation of site response is Horizontal-to-Vertical Spectral Ratio method (HVSR, Nath et. al, 2005; Lermo and Chavez-Garcia, 1993). The method also estimates frequencies and amplitude of fundamental resonance peaks. The traditional spectral ratio method employs a reference site – rock site with response assumed to be close to 1. On the other hand, the GINV technique does not involve any reference site but employs inversion approach in solving a kind of over-determined problem. In the case of an alluvial region, site response can be also computed from geotechnical data. Combining wave propagation theory with the material properties, the expected ground motion can be computed at the site of interest. Several software (SHAKE, SHAKE2000, WESHAKE, ShakeEdit, etc) are available for seismic response analysis for horizontally layered soil deposits in which recurrent and circular soil behavior can be simulated using linear equivalent model (Kramer, 1996).

The geological characteristics of the Sikkim Himalaya and the Guwahati city represent two contrasting features - hilly terrains and alluvial basin respectively. In hilly region, most of the contribution in the site amplification of motion comes from the radiation pattern and topography of the area while in flat terrains, soil thickness and near surface low velocity stratigraphy attributes to ground motion amplification. The amplification of ground motion over soft sediments occurs fundamentally due to the trapping of seismic waves and the resulting impedance contrast between sediments and the underlying bedrock. These trapped waves interfere with each other to produce resonance patterns, the shape and the frequencies that are correlated with the geometrical and mechanical characteristics of the structure.

Site amplification in the Sikkim Himalaya has been attributed mainly to different source radiation patterns, scattering, diffraction and undulating topographic effects. Soil thickness in the region is shallow while shear wave velocity is relatively high due to rock exposure. Site amplification study in the region with HVSR and GINV techniques by Nath et al. (2005) based on 80 local earthquakes ($3 \leq ML \leq 5.6$) recorded during 1998 -2003 with good signal-to-noise ratio (≥ 3) by IIT Kharagpur Sikkim Strong Motion Array (SSMA) comprising of nine stations across the terrain. The azimuthally dependent site response at all the stations from two different techniques exhibited similar trends with minor or no variation at all in the amplitude of the respective site response curves. Accordingly, the distribution of site response and the corresponding predominant frequency, as depicted in Figs 3(a) and (b), could be achieved.

On the other hand, The Guwahati city is covered with recent alluvium with some Archean

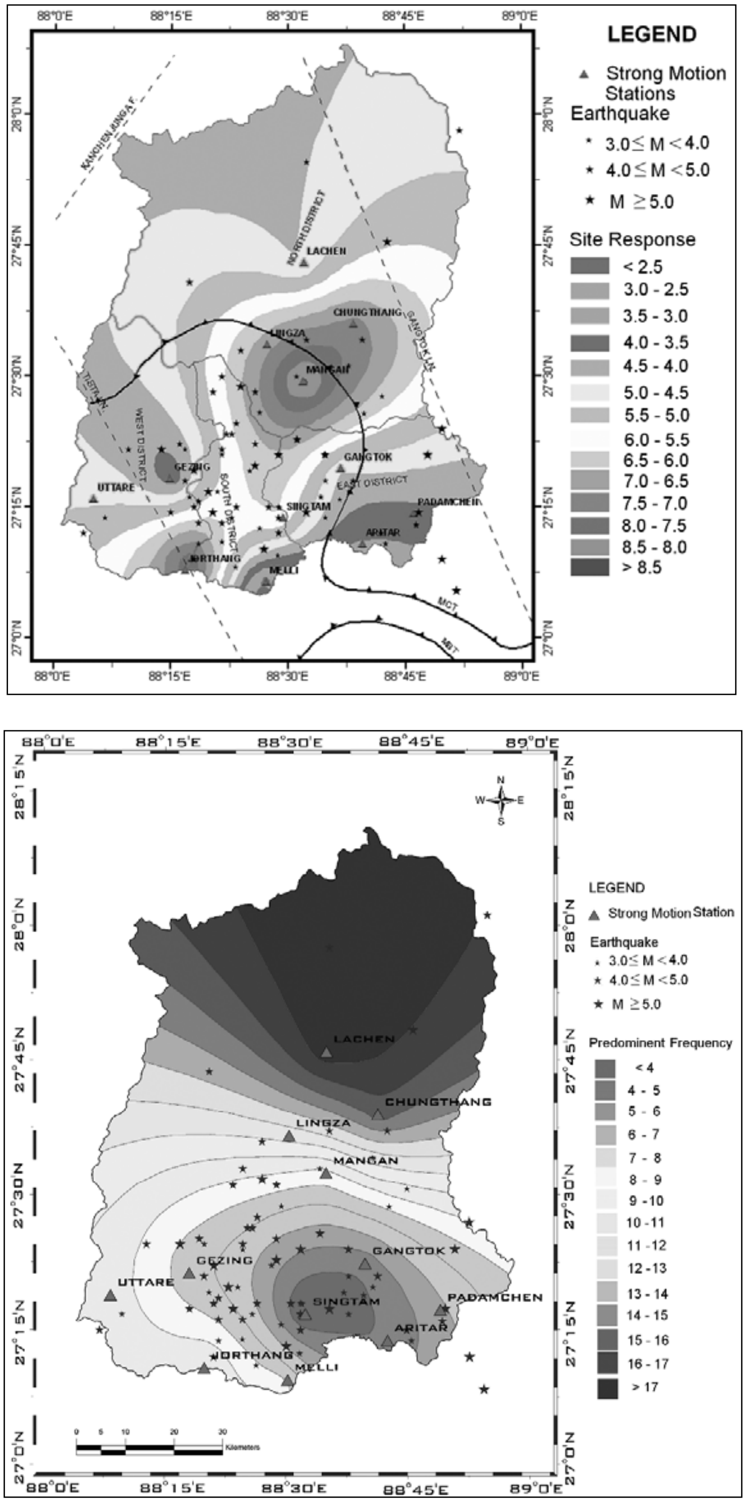
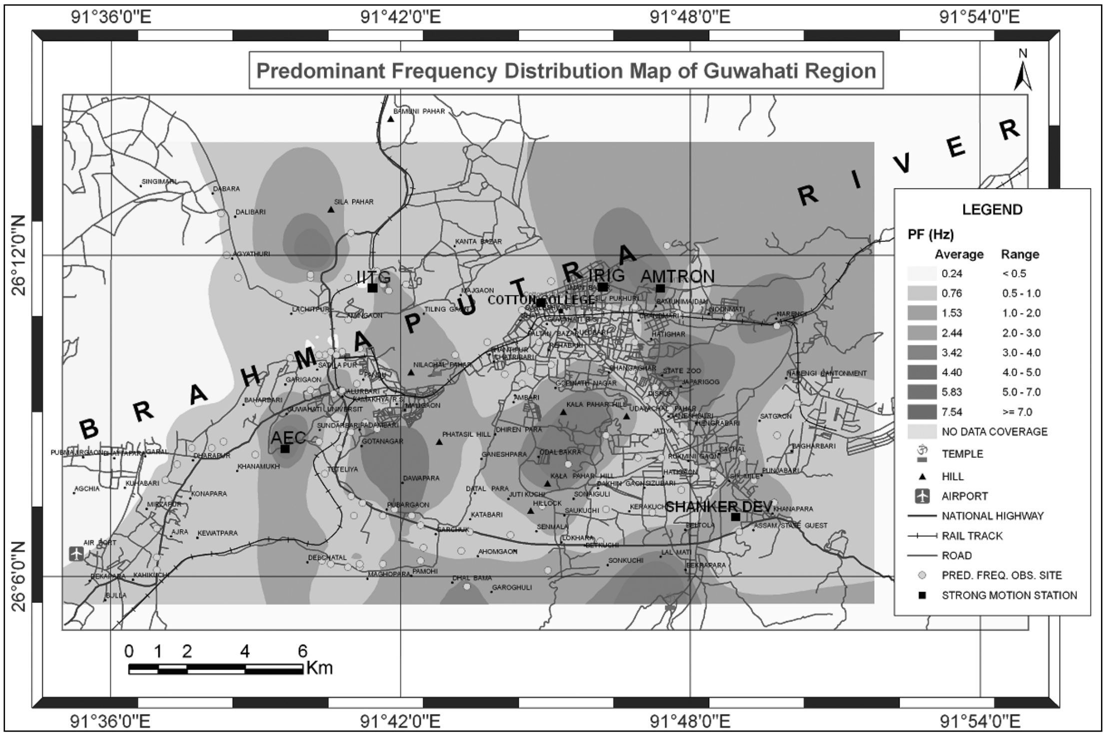


Figure 3: (a) Site response distribution corresponding to the predominant frequencies, and
(b) Predominant frequency distribution maps of the Sikkim Himalaya.



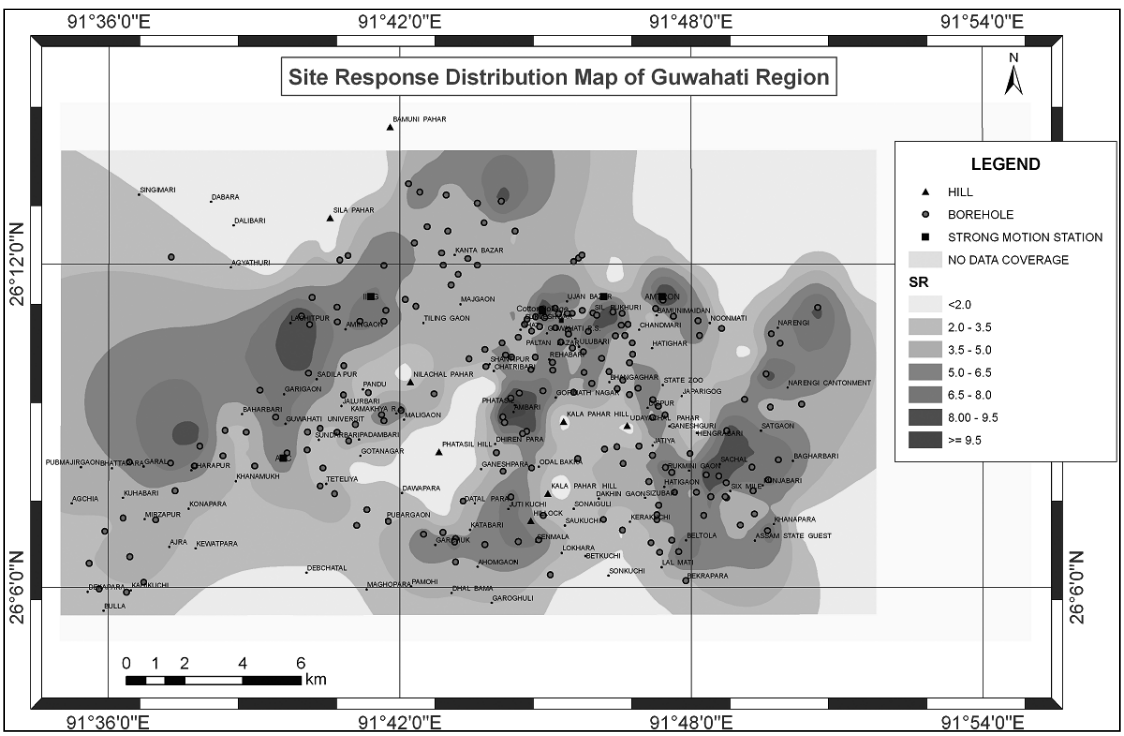


Figure 4: (a) Site response and (b) Predominant frequency distribution maps of the Guwahati region.

hillocks exposed at places. The area falls in the Lower Assam valley that consists of crystalline rocks that are covered by gently dipping Tertiary and younger sediments. The sediment thickness varies from ten to few hundred meters in the region, which is the likely contributor of site specific ground motion amplification. Nath et al., (2008) estimated the site response distribution in the region from the geotechnical data at 200 boreholes across the region as well as strong motion data of five events ($4.8 \leq mb \leq 5.4$) that occurred during 2006. The strong ground motion data analyses were achieved through the HVSR technique at different source azimuths for various sites. The geotechnical analyses were performed through WESHAKE91 (Sykora and Wahl, 1992) at all the 200 borehole locations. It has been seen that the estimated site response obtained from both the analyses shows reasonable agreement. Figure 4(a) depicts the site response distribution in the city. Furthermore, predominant frequency distribution in the region, as depicted in Fig 4(b), has been assessed through ambient noise data analysis (Nakamura, 1989) at 141 locations by Nath et al. (2008) and is found to have a reasonable correspondence with the results of the geotechnical and strong motion data analyses.

Table 1: The parameters used for ground motion simulation for the scenario earthquake MW 8.3 for the Sikkim Himalaya and MW 8.7 for the Guwahati region.

PARAMETERS	SCENARIO SOURCE	
	Guwahati	Sikkim
Strike	292°N	310°N
Dip	40°ESE	35°NNE
Focal depth (km)	35	26.3
Source (Lat, Long)	26°N, 91°E	27.25°N, 88.46°E
SEM	8.7	8.3
Fault length (km)	330	250
Fault width (km)	150	80
Sub-faults along Strike	11	12
Sub-faults along Dip	5	4
shear wave velocity (km/s)	3.25	4.0
Crustal density (g/cm^3)	2.7	2.7
Stress (bars)	159	65
Q_S	$342f^{0.72}$	$167f^{0.47}$
Geometrical spreading	1/R (R<100 km)	1/R (R<100 km)
	$1/R^{0.5}$ (R>100 km)	$1/R^{0.5}$ (R>100 km)
Windowing function	Saragoni and Hart	Saragoni and Hart
Amplification	Geotechnical Site response	HVSR

Deterministic Peak Ground Acceleration in Sikkim Himalaya and Guwahati city

A two-tier approach for the ground motion assessment involves the assessment at engineering bedrock and thereafter incorporation of the site effects to provide the ground motion at the surface. In the deterministic hazard computation, actual ground motion is simulated taking a source (fault parameters), a path (crustal structure), and site (weathering layer properties) for an extreme condition, and the peak ground acceleration (PGA) is estimated therefrom. The present case studies are confined to the stochastic methods only. The stochastic approaches provide expedient methods of synthesizing strong ground motion and is modeled as Gaussian noise with a spectrum that is either empirical or physical (Hanks and McGuire, 1981; Boore, 1983; Boore and Atkinson, 1987; McGuire et al., 1984). The stochastic method with finite fault model proposed by Beresnev and Atkinson (1997) divides a fault into several sub-sources that individually act as point source. The method has been further enhanced by Motazedian and Atkinson (2005) through incorporation of dynamic corner frequency. In the present analyses, a FORTRAN code EXSIM for dynamic finite fault simulation (Motazedian and Atkinson, 2005) has been used to simulate peak ground acceleration.

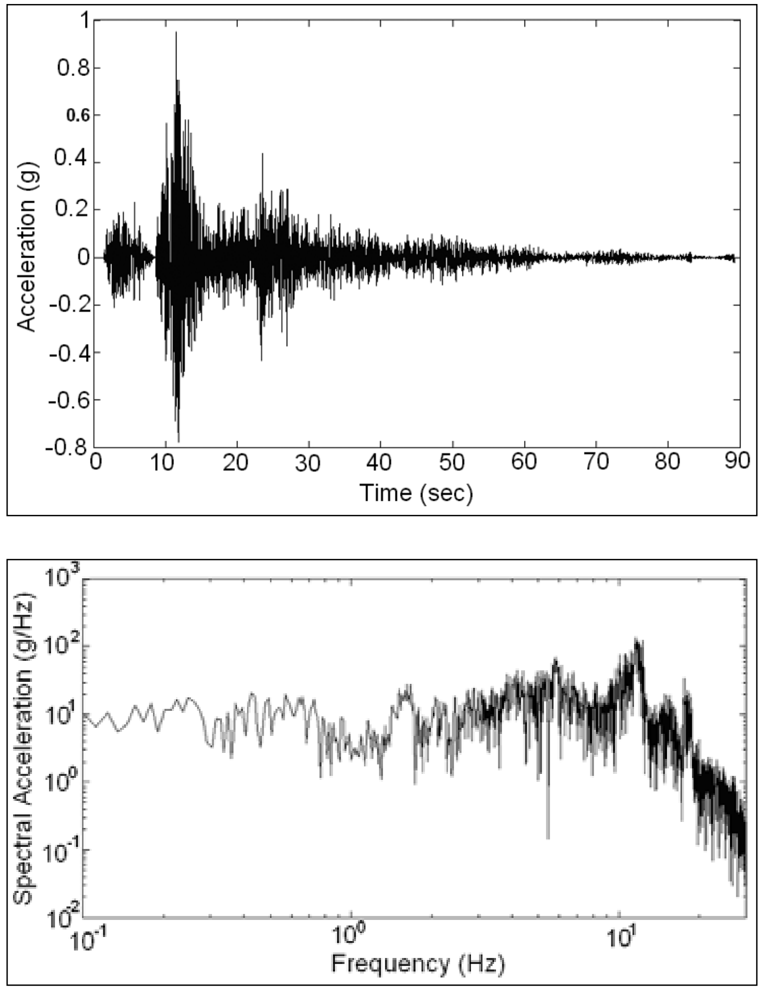


Figure 5: (a) Time domain simulation of accelerogram for the scenario earthquake of MW 8.7 at a borehole located close to AEC. (b) The corresponding accelerogram represented in the spectral domain. (c) PGA distribution map of Sikkim Himalaya for the scenario earthquake of MW 8.3.

The scenario earthquake of MW 8.3 has been designated to be nucleating from the hypocenter of the earthquake occurred on December 2, 2001, ML 5.6, the largest amongst 80 significant events recorded by SSMA. This event occurred just below MBT at a depth of 26.3 km with a composite fault plane solution having 310° strike and 35° NNE dip. The fault area has been computed by

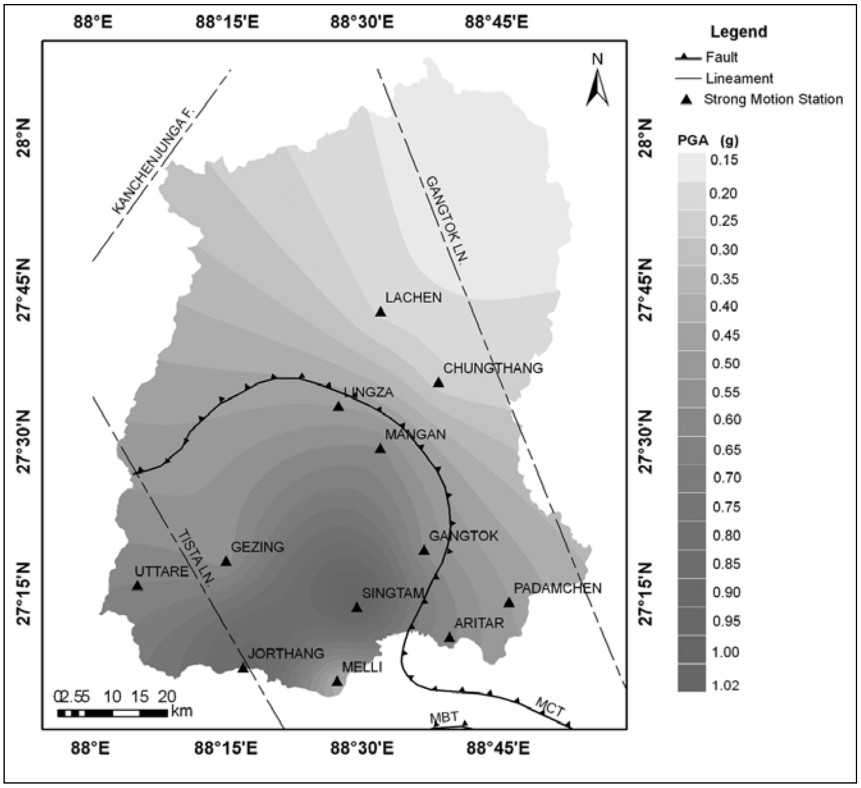


Figure 5: (c) PGA distribution map of Sikkim Himalaya for the scenario earthquake of MW 8.3.

the relation given by Beresnev and Atkinson (2001). The average stress drop can be derived from strong motion data recorded in the area as suggested by Motazedian and Atkinson (2005). Singh et al. (2002) has taken 60 bars for the simulation of big earthquakes on MBT in the northwestern Himalaya. However, considering the distribution of stress drop with magnitude, a value of 65 bars has been found to be quite appropriate for the present deterministic hazard simulation. The quality factor, Q, has been derived from the analysis of all earthquake data (Nath et al., 2005). A tapering windowing function of Saragoni and Hart (1974) has been employed. The simulation parameters have been listed in Table 1. The site response at each strong motion station has been incorporated in the analysis. The synthetic accelerograms for the scenario earthquake of MW 8.3 at Jorthang is depicted in Fig 5 (a) and (b) respectively. The PGA distribution map of the region as presented in Fig 5(c) depicts a maximum value of 1.02g in the Lesser Himalaya while 0.15g has been found in the Higher Himalaya.

On the other hand, the Great 1897 Shillong Earthquake source has been considered for the deterministic seismic hazard scenario generation in the Guwahati region. The strike and the dip of the fault have been taken as 292° N and 40° ESE respectively (Bilham and England, 2001). A fault dimension of 330 x 150 km has been modeled for the simulation considering the extended fault in the region with a stress drop of 159 bars that has been observed for a slip of 16m during the earthquake. The stress drop from the slip value has been computed using relation given in Beresnev and Atkinson (2001). Pulsating area for the computation has been taken equal to 25% of the rapture area (Motazedian and Atkinson, 2005). The quality factor has been adapted from Nath et al. (2008). Accordingly, the simulation parameters have been listed in the Table 1. Taking into consideration the source, site and path effects, PGA values have been computed at all the 200 borehole locations. The geotechnical site response has been considered for the purpose. Figures 6 (a) and (b) depict the simulated accelerograms for the scenario earthquake at a borehole located close to AEC. The PGA distribution map of the region as depicted in Fig 6(c) shows a variation from 0.22g to 1.27g. The high PGA zones have been observed at those sites where site response is considerably higher that could be attributed to reverberations of the trapped energy in the low velocity near-surface soil layer.

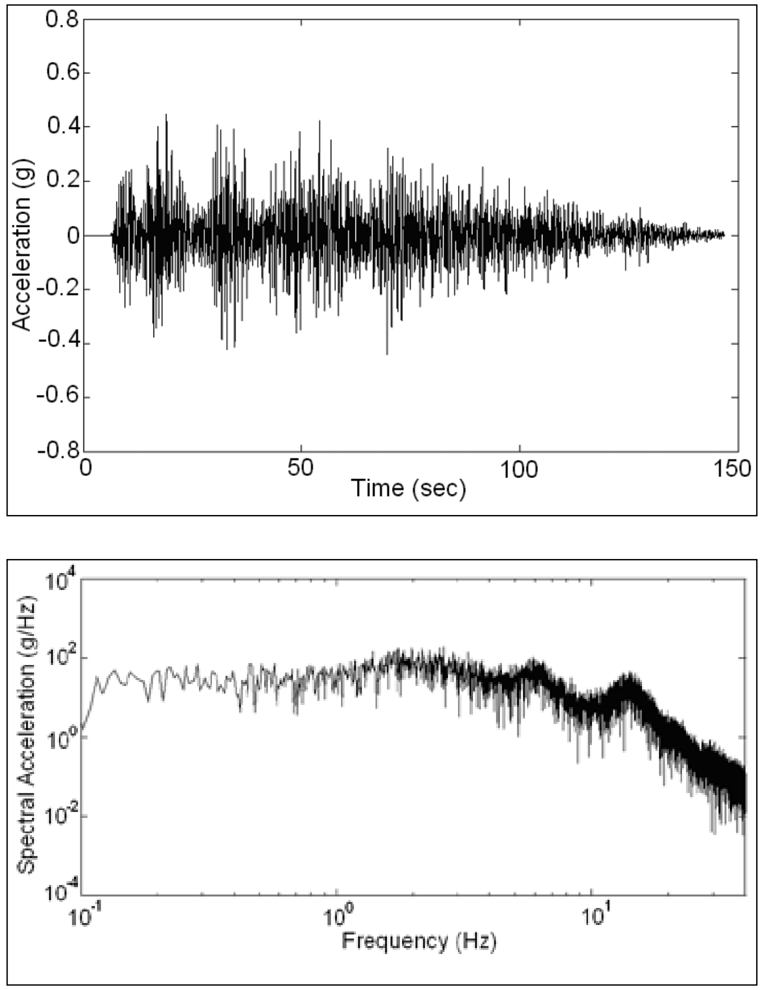


Figure 6: (a) Time domain simulation of accelerogram for the scenario earthquake of MW 8.7 at a borehole located close to AEC. (b) The corresponding accelerogram represented in the spectral domain.

Seismic Microzonation of Sikkim Himalaya

The microzonation procedure, undertaken in the Sikkim Himalaya, follows an initial hazard classification based on the geological hazard components to obtain 'Geohazard' theme, and thereafter the theme is integrated with the seismological themes to achieve the final hazard zonation.

Three geomorphological attributes namely - surface geological units, soil taxonomy, site classification, rock outcrop and landslide has been taken in consideration. The corresponding thematic layers have been adapted into the present study from Nath (2004). The major datasets

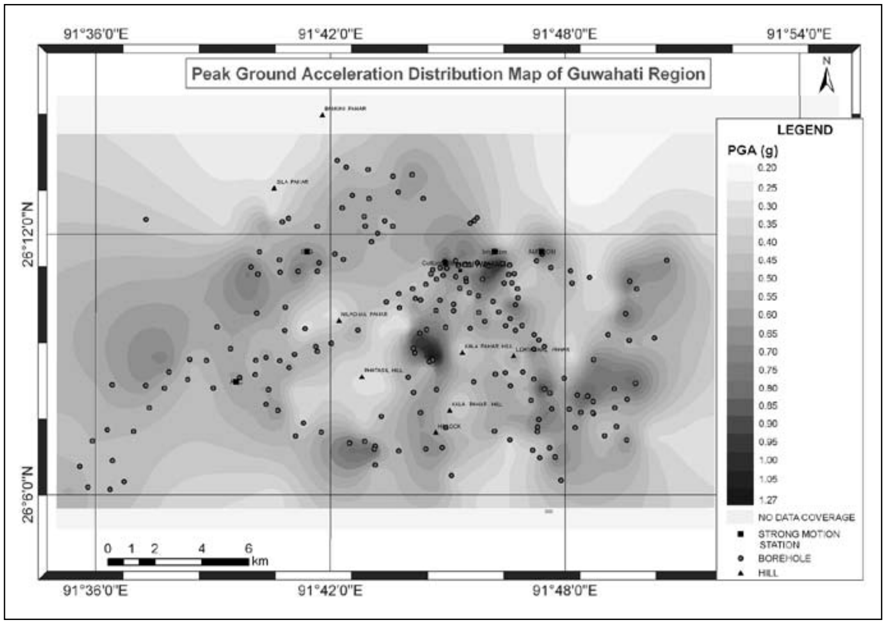


Figure 6: (c) PGA spatial distribution of Guwahati region for the scenario earthquake of magnitude MW 8.7.

include IRS–1C LISS III digital data, toposheets from Survey of India, geographical boundary for the State of Sikkim, surface geological maps, soil taxonomy map from National Bureau of Soil Survey (NBSS, 1994) and seismic refraction profiles. The surface geology (GE) of the region has been depicted in Fig 7(a). The soil taxonomy (SO), in the region, based on composition, grain size and lithology constitutes IB (S-wave velocity, β > 1500 m/s), IC (β = 700-1500 m/s), II (β = 350-700 m/s) and III (β = 180-350 m/s) classifications. The percent slope (SL) mapping has been done with Triangulated Irregular Network (TIN) on GIS. Rock outcrop (RO) and landslide (LS) scarp region had been identified and vectorized into two separate polygon coverage. The landslide zones have been introduced to highlight the relevant hazard conduced from seismic activities rather than landslide hazard zonation through elaborate geotechnical detailing, which is not envisaged in the present study.

The weights assigned to each of the themes along with the normalized ranks assigned to each features of individual themes for the geological hazard estimation as well as final the seismic microzonation layers preparation are listed in Tables 2 and 3 respectively. The Geohazard map is obtained through the integration technique following AHP accounting all the geomorphological coverage via the following equation,

$$Geohazard = \frac{(GE_w \cdot GE_r + SO_w \cdot SO_r + SL_w \cdot SL_r + LS_w \cdot LS_r + RO_w \cdot RO_r)}{\sum w} \tag{1}$$

Table 2 : Normalized weights and ranking assigned to the geomorphological attributes of the Sikkim Himalayan region for thematic integration to compute Geohazard distribution.

Theme	Weight	Feature	Rank
Geology (GE)	0.3333	Biotite and Tourmaline Granite, Daling Metapelite, Buxa Dolomite and Gondwanas	1.0000
		Streaky Biotite granite Gneiss and Darjeeling Gneiss	0.7500
		Tsolhamo Series and Chungthang Calc-Granulite	0.5000
		Kanchenjunga Gneiss	0.2500
		Mt. Everest Limestone and Everest Pelitic Series	0.0000
Soil/Site class (SO)			
	0.2666	IB	1.0000
		IC	0.6667
		II	0.3333
		III	0.0000
Percent Slope (SL)	0.2000	≥ 75	1.0000
		60 - 75	0.8000
		45 - 60	0.6000
		30 - 45	0.4000
		15 - 30	0.2000
		< 15	0.0000
Landslide (LS)	0.1333	Present	1.0000v
		Absent	0.0000
Rock Outcrop (RO)			
	0.0666	Present	1.0000
		Absent	0.0000

Additional subscripts have been added to the notation assigned to each theme to indicate weight and normalized rank with ‘w’ and ‘r’ respectively.

The Geohazard index are suitably categorized into three classes with values ranging between 0.0 to 0.35 quantitatively termed as Low Hazard, 0.35 to 0.55 termed as Moderate Hazard, and greater than 0.55 assigned a qualitative definition as High Hazard. The Geohazard map of the Sikkim Himalaya is presented in Fig 7(b), wherein the high hazard region is seen to dominate the lesser Himalaya, moderate and intermediate hazard region in the terrain between the lesser and higher Himalaya Crystalline (Fig 7a) just above MCT, while the higher Himalaya exhibits low Geohazard index.

The vector union operation is subsequently performed on the seismological themes. The seismological attributes (detailed in Section 3) considered for thematic mapping include predominant frequency (PF) as depicted in Fig 3(b) and surface consistent peak ground acceleration (PGA) as

Table 3: Normalized weights and ranking assigned to the seismological and Geohazard attributes of the Sikkim Himalayan region for thematic integration to achieve seismic microzonation.

Theme	Weight	Feature	Rank
Simulated Peak Ground Acceleration (PGA) in g	0.5000	0.40-1.0	1.0000
		0.25-0.40	0.6667
		0.20-.25	0.3333
		<0.2	0.0000
Predominant Frequency (PF) in Hz	0.3333	<4	1.0000
		4.0-5.0	0.9285
		5.6-6.0	0.8571
		6.0-7.0	0.7857
		7.0-8.0	0.7143
		8.0-9.0	0.6428
		9.0-10.0	0.5714
		10.0-11.0	0.5000
		11.0-12.0	0.4286
		12.0-13.0	0.3571
		13.0-14.0	0.2857
		14.0-15.0	0.2143
		15.0-16.0	0.1428
		16.0-17.0	0.0714
		>17.0	0.0000
Geohazard	0.1667	>0.55	1.0000
		0.35-0.55	0.5000
		<0.3	0.0000

depicted in Fig 5(c). A holistic earthquake hazard model evolved in this analysis delivering the output seismic microzonation theme follows the relationship,

$$\mathrm{EHI} = \left(\begin{array}{l} \mathrm{PF_w.PF_r + PGA_w PGA_r} + \\ \qquad \mathrm{GE_w GE_r + SO_w SO_r + SL_w SL_r + LS_w LS_r + RO_w RO_r} \end{array} \right) / \sum w \tag{2}$$

where EHI stands for Earthquake Hazard Index. The seismic hazard microzonation map as depicted in Fig 8 classifies the Sikkim Himalayan territory into six broad hazard zones. Qualitatively, we termed this classification - ‘Low’ with hazard index less than 0.2, ‘Moderate’ between 0.2 to 0.4, ‘Moderately High’ between 0.4 to 0.6, ‘High’ between 0.6 to 0.8, and ‘Very High’ greater than 0.8 encompassing Gangtok, Singtam, Aritar, Jorthang, Gezing, Melli, Padamohen, and touching

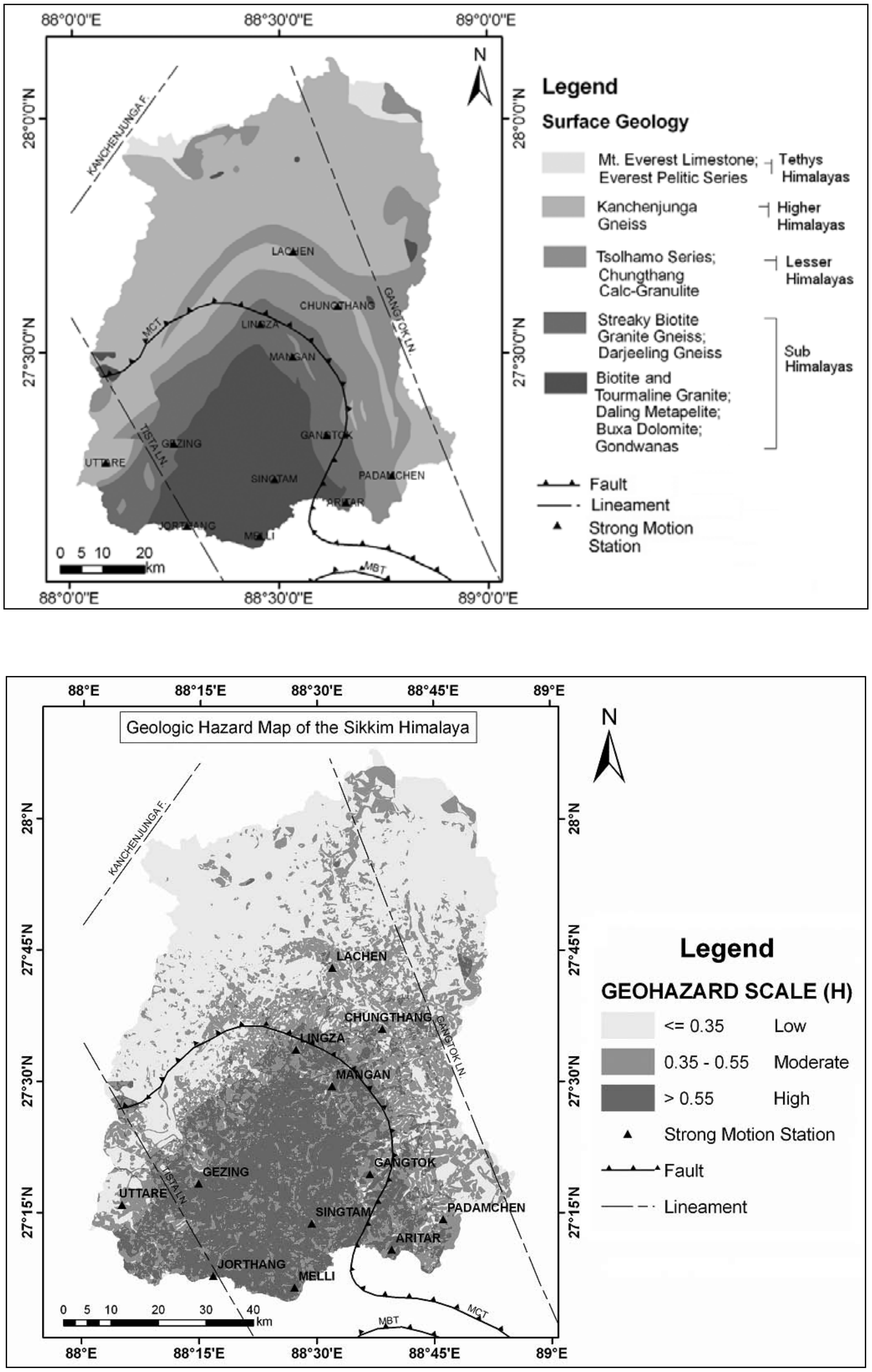


Figure 7: (a) Surface geological and (b) the Geohazard maps of Sikkim Himalaya respectively.

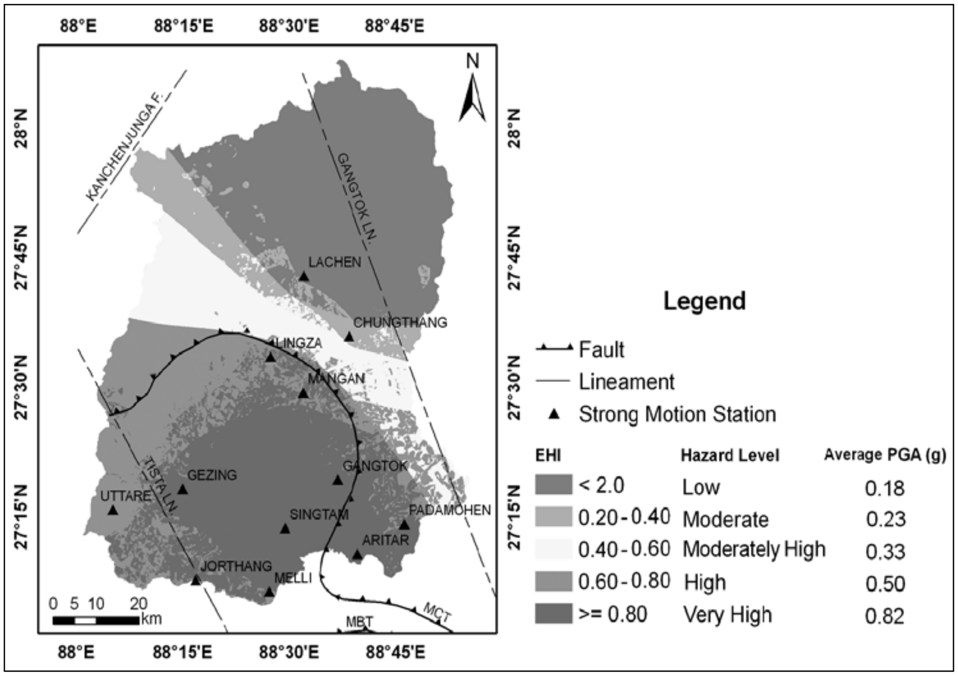


Figure 8: Seismic microzonation map of Sikkim Himalaya.

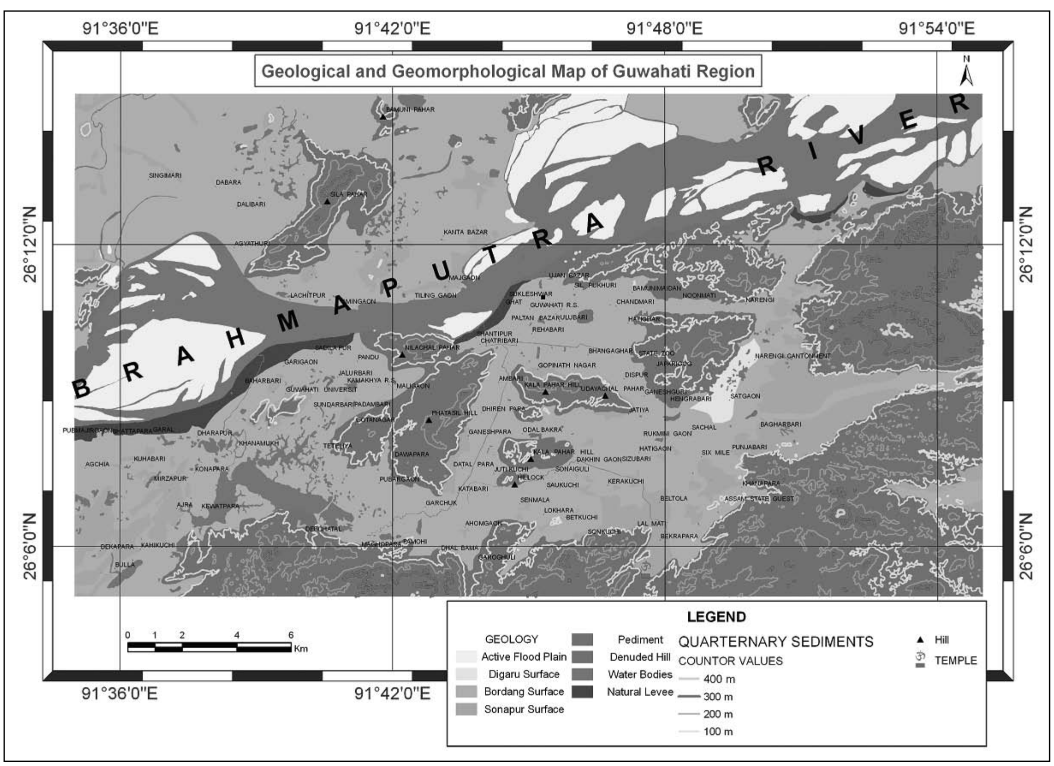
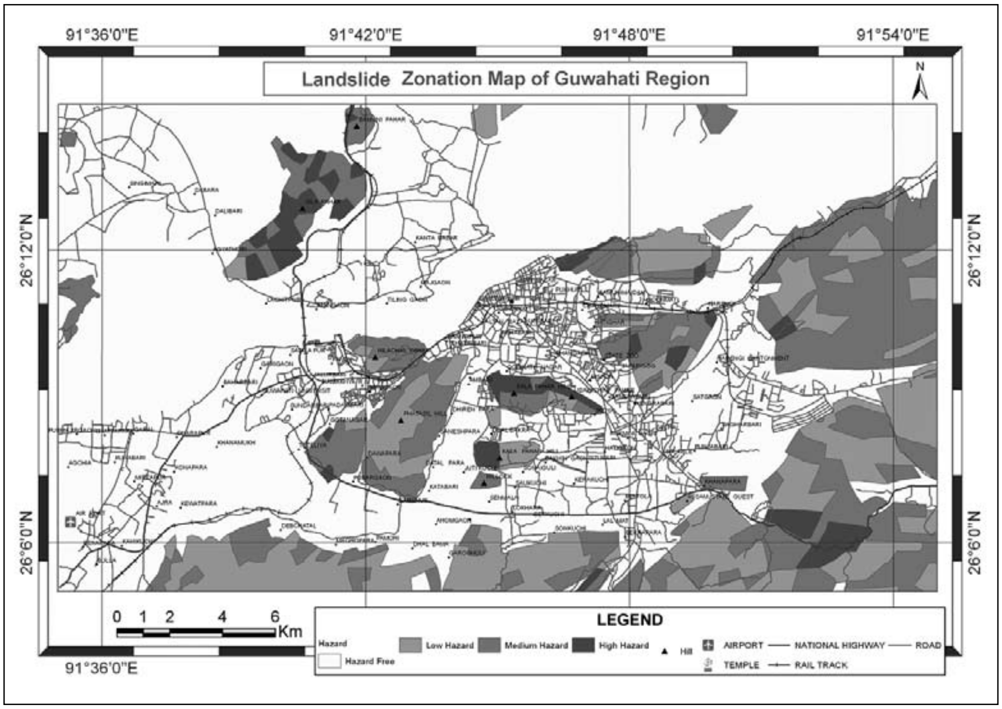


Figure 9: (a) The geological and geomorphological



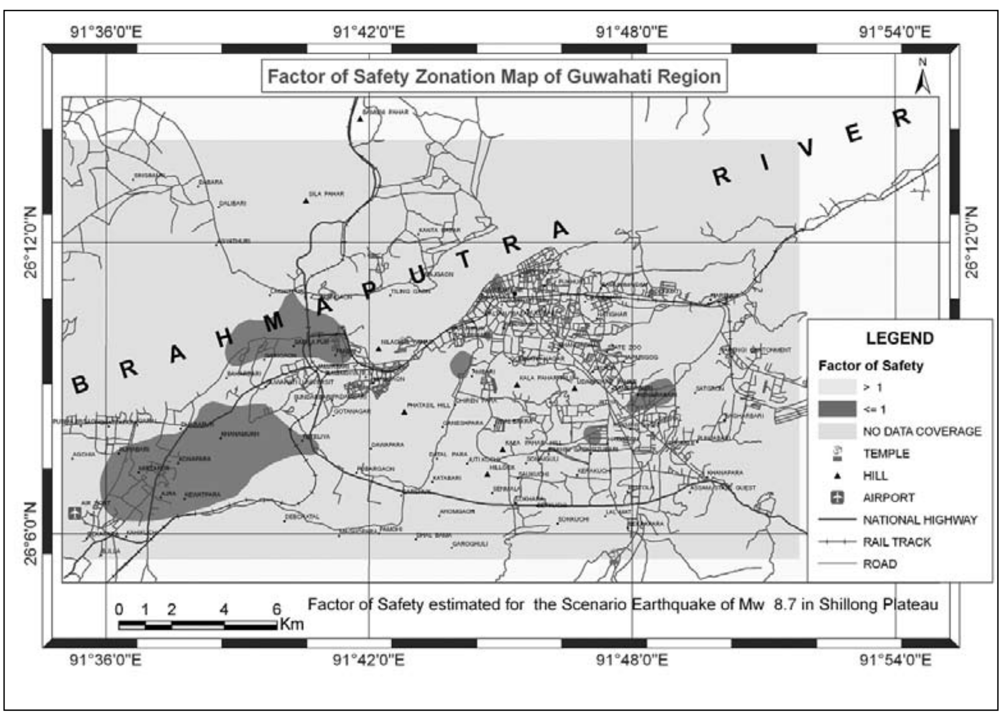


Figure 9: (b) landslide zonation and (c) factor of safety zonation maps of the Guwahati region respectively.

Mangan and Lingza as well. The average PGA has been drawn for each classification with 'Low', 'Moderate', 'Moderately High', 'High', and 'Very High' corresponding to 0.18g, 0.23g, 0.33g, 0.50g, and 0.82g respectively. Although the present PGA specifications are surface consistent unlike the BIS provision that are provided for bedrock level, it can be seen that the zones - 'Low', 'Moderate', and 'Moderately High' falls in the Zone IV of the BIS nomenclature, according to the PGA ranges identified for the BIS zones by Jaiswal and Sinha (2007). 'High' zone corresponds to the BIS Zone V while the average PGA for 'Very High' zone is seen higher than the maximum specified for the Zone V.

Seismic Microzonation of Guwahati City

The microzonation study of the Guwahati city, as pointed out earlier, presents a case of basin geology in contrary to the hilly terrains of Sikkim Himalaya. We have considered the following eight hazard themes:

(i) Geological and Geomorphological (GG),
(ii) Basement or bed rock formations (BM),
(iii) Landuse (LU),
(iv) Landslide (LS),
(v) Factor of Safety (FoS),
(vi) Shear wave velocity ( ),
(vii) Predominant Frequency (PF), and
(viii) Surface consistent Peak Ground Acceleration (PGA).

The various thematic layers have been presented by Nath et al. (2007). The GG map as depicted in Fig 9(a) depicting the major aggradational units identified as active flood plain and Levee deposits, and the Digaru, Bordang, Sonapur, and Pediment surfaces respectively. The basement (BM) or bed rock formations map for the region has been prepared by examining the results of vertical electrical resistivity sounding surveys carried out by Geological Survey of India (GSI) during 1986-88 and 2002-03, and the data obtained from 30 boreholes. The LU map has been derived from the land use pattern from the SOI toposheets of 1986-87 along with recent satellite imageries of the area. LS zones as depicted in Fig 9(b) have been demarcated in the region using slope angle, lithological structures, relative relief, landuse cover, hydrological correlation, seismicity, rainfall, and landslide incidences. As in the previous case, the LS zones present the relevant hazard due to seismic activities. The shear wave velocity distribution has been obtained from Standard Penetration Test (SPT) data at 200 borehole sites across the region (Nath et al., 2008). The variation of Vs-30 from 200m/s to 360 m/s as observed in the region falls under site class III (Nath et al., 1997), which is further categorized into four subclasses with variation of 40 m/s. This consideration has been entirely local specific to enable highlighting the variation, however minor it is, into the integration process.

Geological Feature	Predominant Frequency (Hz)
Active Flood Plain and levee	<= 0.5
Digaru Surface	0.5 - 0.8
Bordang Surface	0.8 - 2.0
Sonapur surface	2.0 - 4.0
Rocky areas of Pediment	4.0 - 6.0
Denuded Hill	> 6.0

As such the sub-classification has been seen to have a reasonable correlation with the geological traits across the study region. Furthermore, the shear wave velocity contribution is evident from the significant variation associated with the predominant frequency across the terrain. Table 4 presents the predominant frequency distribution pertaining to the various geological attributes.

The Factor of Safety represents soil stability against the liquefaction hazard. The Guwahati region being situated in the Brahmaputra basin, the pertinent soil conditions are rather hydrologically expansive and well-endowed aquifers. The parameter is estimated as the ratio of maximum to actual load sustainability at each of the borehole locations determining safe and unsafe zones. The maximum load is represented by the earthquake load given by cyclic stress ratio (CSR) while the actual load is characterized by the in situ parameters obtained from SPT N value assessment method quantified as cyclic resistance ratio (CRR). Following Seed and Idriss (1971) and Seed et al. (1985), CSR can be calculated from the following equation

$$CSR_{7.5}=0.65\frac{r_d}{MSF}\frac{a_{max}}{g}\frac{\sigma_o}{\sigma_o'} \tag{3}$$

where CSR7.5 is the CSR for an earthquake of MW 7.5, amax denotes the maximum ground acceleration for the scenario earthquake, g is acceleration due to gravity, σo is the total overburden pressure, σ¬o′ is the effective overburden pressure. The average stress reduction factor, rd, is estimated through Liao et al. (1988) relations that correlates with the depths below surface. The magnitude scaling factor, MSF, has been obtained from the relationship between the earthquake moment magnitude (MW) and MSF given by Idriss (1999).

The SPT N values has been corrected accounting for the effect of hammer energy and effective stress on boring according to suggestions of Seed et al. (1985) to obtain $(N1)_{60}$ values. Thereafter, the cyclic resistance ratio corresponding to earthquake of M_W 7.5 is computed through the equation given by Idriss and Boulanger (2005),

$$CRR_{7.5} = \exp\left\{\frac{(N_1)_{60}}{14.1}+\left(\frac{(N_1)_{60}}{126}\right)^2-\left(\frac{(N_1)_{60}}{23.6}\right)^3+\left(\frac{(N_1)_{60}}{25.4}\right)^4-2.8\right\} \tag{4}$$

The Factor of Safety zonation map, finally, achieved has been depicted in Fig 9(c).

Table 5 : Normalized weights and ranks assigned to each feature of the thematic maps for thematic integration to achieve seismic microzonation. The themes and features are presented in descending order according to the weights and ranks respectively.

Theme	Weight	Feature	Rank
Geology (GG)	0.2222	River ,Water Bodies & Swampy area	1.0000
		Active Flood Plain	0.8571
		Natural Levee	0.7143
		Pediment	0.5714
		Sonapur Surface	0.4286
		Digaru Surface	0.2857
		Bordang Surface	0.1429
		Denuded Hills	0.0000
Basement (BS) in metres	0.1944	> 600	1.0000
		500 - 600	0.8333
		400 - 500	0.6667
		300 - 200	0.5000
		200 - 300	0.3333
		100 - 200	0.1667
		< 100	0.0000
Landslide (LS)	0.1556	High Hazard Zone	1.0000
		Medium Hazard Zone	0.6667
		Low Hazard Zone	0.3333
		River, Sand Bar & Hazard Free Zone	0.0000
Landuse (LU)	0.1667	Residential Area	1.0000
		Educational, Army/Police Reserve, Commercial area	0.8333
		Sandbars ,River Island & Swampy area	0.6667
		Field/ open space & Agricultural Area	0.5000
		Residential Areas in Hill	0.3333
		Hill with dense & light forest	0.1667
		River, water bodies/Beel	0.0000
Shear Wave Velocity (Vs30) in m/s2	0.1111	200 - 240	1.0000
		240 - 280	0.6667
		280 - 320	0.3333
		320 - 360	0.0000

Theme	Weight	Feature	Rank
Peak Ground Acceleration (PGA) in g	0.0833	1.00 -1.30	1.0000
		0.40 - 0.10	0.6667
		0.25 - 0.40	0.3333
		0.20 - 0.25	0.0000
Predominant Frequency (PF) in Hz	0.0556	< 0.5	1.0000
		0.5 - 1.0	0.8571
		1.0 - 2.0	0.7143
		2.0 - 3.0	0.5714
		3.0 - 4.0	0.4286
		4.0 - 5.0	0.2857
		5.0 - 7.0	0.1429
		> 7.0	0.0000
Factor of Safety (FoS)	0.0278	≤ 1	1
		> 1	0

Eventually, integration of the thematic layers following AHP is performed to obtain the hazard index representing seismic microzonation for the region. As with the previous case, weights are assigned to each of the aforesaid themes according to their relative importance. The normalized ranks to each of the features of the individual themes are also assigned within each theme, as well. The normalized weights and ranks are listed in Table 5.

The seismic hazard microzonation map thus obtained represents the integration of all the aforesaid themes in the following relation

$$EHI = (GGwGGr+ BMwBMr + LSwLSr + LUwLUr + Vs30w\ Vs30r+ PGAwPGAr +PFwPFr + FoSwFoSr)/\Sigma w \quad (5)$$

The notations have their usual meanings.

The seismic hazard microzonation map as shown is Fig 10 exhibits five zones with the EHI corresponding to less than and equal to 0.2, 0.2-0.3, 0.3-0.4, 0.4-0.5 and above 0.5. We termed these zones as ‘Low’, ‘Moderate’, ‘High’, ‘Moderately High’ and ‘Very High’ hazard regions. The ‘Very High’ hazard zone covers patches of the western part of the region wherein active flood plain with Pediment, Sonapur and Bordang surfaces are the prevailing geology and the PGA distribution goes from 0.5 g to as high as 1.3 g. A small zone of ’Very High’ hazard is also seen on the north along the tracts of the Brahmaputra river. On the other hand, high hazard zone with PGA

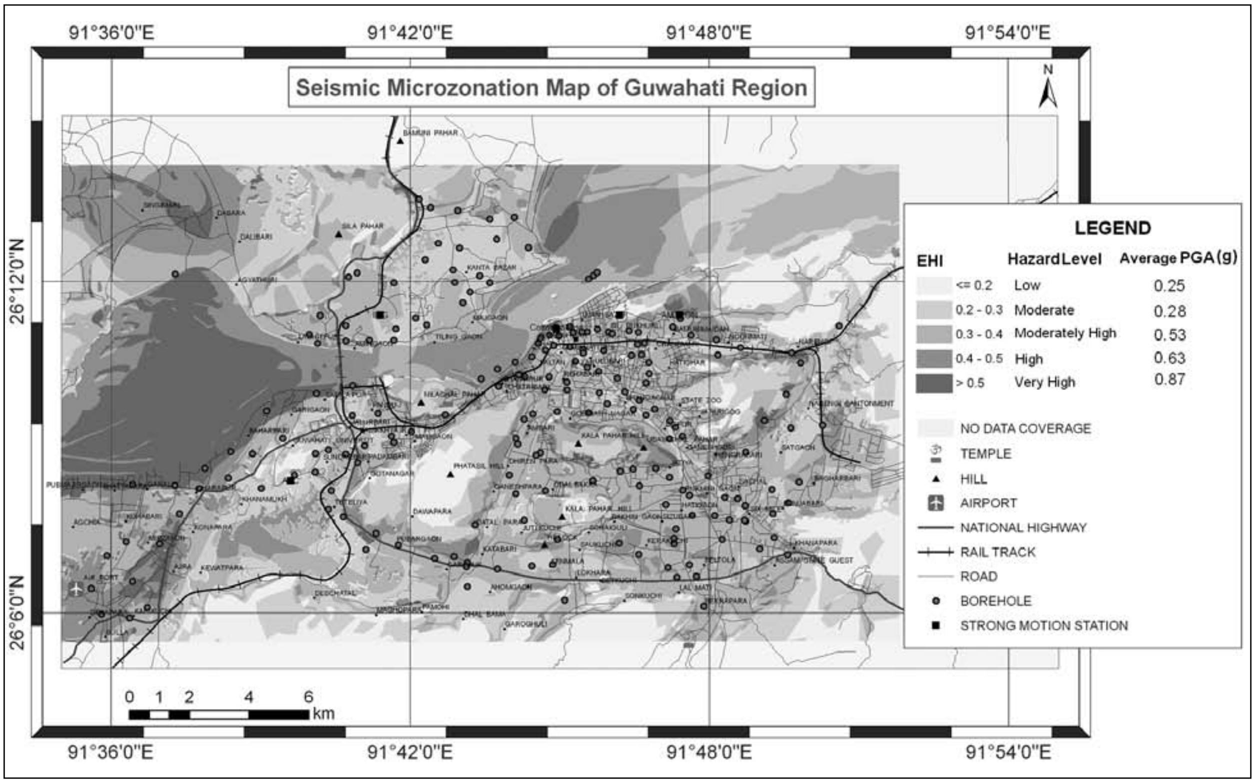


Figure 10: Seismic microzonation map of Guwahati region.

distribution of 0.4 - 0.5 g is across the areas of flood plain zones, Sonapur surface, water bodies and pediment covering areas. ‘Moderately High’ hazard regions are seen mostly with water bodies, natural levee, Bordang surface, Sonapur covering areas across the region. Moderate hazard zone is predominantly Pediment and Sonapur surface adjoining the hillock areas with PGA distribution of 0.25-0.40 g. Low hazard zone exhibits relatively low PGA value around 0.20-0.25 g encompassing mostly hillock areas and some part of the eastern region. The hazard zones - ‘Low’, ‘Moderate’, ‘High’, ‘Moderately High’ and ‘Very High’ could be roughly accorded with average PGA of 0.25g, 0.28g, 0.53g, 0.63g, and 0.87g respectively. As in the case of Sikkim Himalaya, the zones can be correlated to the BIS provisions with ‘Low’ and ‘Moderate’ zones falling within Zone IV. ‘High’ and ‘Moderately High’ can be clubbed into Zone V. The average PGA for ‘Very High’ zone is similarly seen higher than the maximum specified.

Discussion and Conclusions

Assessment of earthquake hazard involves persistent and consorted efforts towards regional hazard perspectives to local specific observations. Regional level seismicity analysis performed in the northeast India delivered a broad segregation of four seismic source zones namely EHZ, MBZ, EBZ, and SHZ. Application of maximum likelihood method to estimate maximum earthquakes in each of the source zones presented mmax values of MW 8.35 (±0.59), MW 8.79(±0.31), MW 8.20(±0.50), and MW 8.73 (±0.70) corresponding to EHZ, MBZ, EBZ, and SHZ respectively. The local specific seismological analysis included estimation of predominant frequency, site response, and ground motion simulation to predict peak ground acceleration. The cases of contrasting geological settings that of hilly terrains in the Sikkim Himalaya and that of alluvial basin in the Guwahati City have been examined and presented.

Microzonation delivers seismic hazard maps on an urban block-by-block scale which is based on local conditions that affect ground-shaking levels or vulnerability to soil liquefaction. The pertaining studies broadly aim to estimate amplification differences of ground motion at different sites.

The study presented five zones of varying hazard levels, in the Sikkim Himalaya, of which the associated average PGA not only expressed accordance to the BIS Zone V in the region but also implicated higher PGA than that implicated by the BIS zonation in the region that otherwise has been placed entirely under Zone IV by BIS codal provision. On the other hand, it has been seen in the Guwahati city, the hazard zonation highlighted presence of BIS Zone IV in the region which otherwise has been entirely placed under the highest classification of Zone V. The region has been also seen with average PGA values much higher than the BIS provisions. These hazard maps, therefore, deliver enhanced detailing with a better representation of the local specific seismic hazard variation.

The results of the case studies presented here signify an outlook on seismic hazard assessment that is local specific and is based on incorporation of different facets of the seismic hazard. The implications arising out of these hazard specifications need to be addressed. The microzonation projects are aimed at development of hazard maps that represent a cognizance of the prevailing seismic hazard in the study regions. These maps are useful in areas of landuse planning, structural engineering, development projects, and action planning specific to seismic hazard mitigation. A major task is to bring forth relevant local specific construction codes from the microzonation outputs. The results of the scientific efforts should be delivered to the society through designated government bodies or non-government organizations. Thus, any microzonation project should culminate in the dissemination of results for maximum societal benefits.

It may be noted that the microzonation efforts needs recurrent investment as such there is always a scope for further examination with more data and enhanced techniques. Microzonation projects involve various experts from geology, seismology, geotechnical to GIS specializations. Furthermore, data collection and preparation forms a major part of the microzonation venture. Therefore, supports from various public as well private organizations are required. Consorted efforts and mutual cooperation must exist in this continual effort towards enhancing our understanding of the seismic hazard problem, and accordingly, work out the response spectra of the designated hazard regions to update the Universal Building Codal provisions over and above the BIS codal practices for necessary updating of the design spectra for appropriate urbanization procedures.

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Seismic Microzonation of Guwahati Urban Agglomeration Vis a vis Risk Mitigation

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Introduction

The North Eastern region of India has already been known to the people as a hot spot of earthquake on the basis of geological , geomorphological, tectonic and seismotectonic setting point of view. The region has also been scientifically classed as Zone V (High seismic Zone) by BIS. Further the past occurrence of disastrous earthquakes of 12th June 1897 Shillong Earthquake and 15th August, 1950 Assam Earthquake enriches our confidence of calling NER of India as high seismic risk / hazard zone. Considering the global and national scenario of recent past earthquake occurrence and its effect NE region has gained its attraction to the various scientists, planners, designers, media and never the less techno administrators and politicians.

A comparative study of past experience of NE region with that of Stable continental Region (SCR Zone II - IV) and Western Himalayan (Zone II-V) it can be seen that technically moderate hazard zones (III) has shown high hazard risk resulting into need of reanalysis of risk factor and plan for risk factor reduction. Such risk evaluation has gained significant importance in NER in recent times owing to the (i) urban centric nature of population (ii) want of space in time (Vertical growth of Exposures) (iii) closer assimilation of population (haphazard growth of Urbanization) and of course non availability of strict stricture of building / development code for construction communication electricity, development of water and its management and so on.

During the last 25 years from 1987, six damaging earthquakes have struck India of which 3 are from Himalayan domain and three are from in Peninsular domain. The major earthquakes that rocked North East corner of India are shown in Table – 1 and only two 1897 & 1950 (op. cit) caused disastrous and rest have caused moderate damage. But with the increasing trend of urbanization the present day risk would increase many fold to that of 1897 &1950 ; it is in this context that risk evaluation and management of different urban areas of NER of India attains significant importance. Further on the basis of statistical analysis as well as characteristic of earthquakes behaviour, various scientists have indicated a due for large earthquakes in NER since 1984, like on the basis of decrease in b- value, (Gupta & Singh), seismic gap (Kayal, 2001) diminution of ts / tp ratio with time. Besides many publicity hungry scientists caused panic and loss of time and economy by giving false prediction in NER.

However the record of past 115 years and historical records have given enough scope of understanding our seismic environment(hazard). Further scientifically, with gradual up gradation of geological, seismological, geophysical, seismotectonic knowledge of NER, it has been confirmed that the region belongs to high seismic hazard zone and the region will face severe event any day at any time which can not be ascertained with our present day know how. Further it can't be prevented nor there is any probability in near future for accurate and socially useful short term prediction for an impending earthquake. Under such circumstances it is imperative that proactive initiatives have to be taken to minimize the primary and secondary effects arising from large event of earthquakes. The solution probably lies on effective strategies through scientific prognostication of active source zone, site condition and its response to severe shaking during different dynamic energy condition, of course awareness, preparedness and mitigation measures for combating earthquake related hazards (seismic hazards). Studies of active fault and seismic hazard assessments (SHA) of any site would probably constitute the major subject of concern, because of society's need to assess the severity and probability of effects during future earthquake.

With this background the author carried out a preliminary seismic microzonation of Guwahati Urban area under the aegis of Geological Survey of India for DST. Following is a brief finding of the studies and the same may judiciously be applied or utilized while preparing mitigation and management development plan of Guwahati Urban area and similar methodology may help elsewhere in NER.

The Guwahati Urban City, lately known as Metropolitian City of North East Region (NER) of India is spreading over an area of about 600 Sq. Km. (Plan 2001). The Guwahati city, being the largest city of NER, is well connected by rail, road air, and inland water route with all the metros of India and acts as a transit point for all other North Eastern States of India as well as South East Asian countries and also known as Gate Way of North East India. The city is also famous for its scenic beauty being located on the bank of mighty river Brahmaputra and with many isolated low height hilltops (Inselbergs) having bounty full of tourist spots like Kamakhya temple, Nabagraha temple, river island Umananda, Bashistha Muni's temple, Balaji temple, Kalakhsetra, Dol Govinda temple, Assam Silk Village at Suanlkuchi, Poa mucca at Hajo and many more other interesting spots (Plate I).

Till recent past (1961) the Guwahati city was having population of only 1,66,695 but with gradual increase of population due to various reasons, like increase in leaving standard, want of job, business and industrialization, population has grown to 8,09895 by 2001 (Table: 1) and crossed 10,00000 population by 2005, besides, recent spurt of infiltration by foreign nationals to this region has changed the demographic profile (Plate IIA) of the city leading to think over the hazard and risk factor due to various natural disasters. For obvious reasons, most of the cultivable as well as low lying wet land mass have been captured for habitation and many multistoried (+ 5 storied) buildings have been constructed without giving much weight age to different risk factors.

Further, the isolated inselbergs (Hill mounds) and well demarcated forest land under the Classified Green Belt zone within the city have been captured by habitants without proper planning and made the area more vulnerable for land slides and enhancing the hazard and risk factor even for the scientifically demarcated low hazard zones.

Physigraphy and Geomorphology of Guwahati Area

Regionally the area forms part of the northern flank of Shillong plateau with intervening depression covered by quaternary alluvial sediments. The northern margin of the area occupied by wide Brahmaputra valley plain which merged with Himalayan foothills followed by E-W trending Himalayan hill ranges. The Brahmaputra River, having world's 4th large water resources (19.83X 103 m3 s-1) is the major trunk channel passing through Guwahati Urban area. It passes through the northern part the present study area flowing westward in a wide braided valley of about 5 Km width in the north east of Guwahati and narrows down to a Km. Near Pandu and again widens to about 4.8 km. near Palasbari. The river changes its flow trend from N – s to NW – SE and than N-S and finally NW. The other prominent drainage in the area is Bashistha River originating from Meghalaya hill ranges in the south and draining into deepar Bill after passing through younger alluvial surfaces of Quaternary period. The prominent Bharalu River originating from Khanapara passes through Zigzag way between Japorigog and Kalapahar hill. Taper Bill is also fed by small streamlets from Amchang hill and back water of Brahmaputra during monsoon.

Physigraphically the area is having following landforms: (Plate: III)

1. Structural controlled, Rocky Isolated Hillocks i.e. each hillock is separated by a fault, which later, due to tectonic disturbances developed depression called 'Bill" along the fault.
2. The valley filled alluvial surfaces of three phases, which can be discernable by level of occurrence, degree of oxidation of the covered surfaces, lithological variations and maturity of the sediments.
3. Levee deposits on the bank of the river
4. Slope surfaces are covered by thick regolithic soil

Geology of Guwahati Area

The area under report comprises two major geological units. The unit – I includes Precambrian rocks, which form the hilly tracts in the south of the area and inselbergs consisting of granite-gneiss, granites and associated meta sedimentaries and basic as well as acidic intrusive rocks. These rocks are well foliated along NE-SW and E-W trends with moderate to steep northerly and southerly dips. Six major sets of joints/ discontinuities are observed trending in NW-SE, N-S, NNE-SSW, NE-SW, ENE-SWS and E-W directions. They are generally vertical to sub horizontal. Some of the trends appear as prominent lineaments, which could be due to deep chemical weathering, often extending beyond 25 m to form a deep regolith or saprolitic cover over the rock, which is overlain by 1 to 3 m thick reddish ferruginous soil capping.

The Unit-II forming Quaternary Alluvium is overlying on an uneven eroded basement of Precambrian rocks. The Guwahati Urban area has grown on the southern part of the westerly flowing Brahmaputra River, while the northern bank is presently under active influence of urbanization. All shallow bore holes (30m) drilled in the area show uninterrupted alluvial sediments from surface to bottom of the boreholes. The deep bore hole drilled (by GSI) in western part of the area at Azara also revealed uninterrupted alluvial sediments up to bottom of the borehole. Maximum thickness of alluvium over basement has been inferred from Bhattapara, Palasbari and Airport areas, and estimated at 250-300m. Subsurface basement topography, as inferred variation in alluvial thickness, is very undulatory, which is described separately in the chapter on ‘Basement Configuration’. Though the city has mostly been built over thick alluvium, i.e. flood plain deposits of Brahmaputra river system yet the haphazard urbanization over isolated hill mounds has changed the topographic hazard scenario with increasing risk factor. The area (Fig. 2) shows six morphostratigraphic units, out of which five are de-gradational and one is Eros ional (Oldest one). The five aggradational surfaces are the traits of the valley and are major concern in the seismic microzonation. In order of increasing antiquity they are (i) Active flood Plain and levee, (ii) Digaru Surface, (iii) Bordung Surface, (iv) Sonapur Surface and (v) pediment surface and constituted by various degree of combination of argillaceous and arrenacious (Sand silt clay).

In the deeper section cyclic repetition of the sediments with coarse clastics, dominating over fines was revealed through drilling. It is noted from bore hole logs that lithological sequence is dominated by flood plain deposit / sediments, Channel lag sediments are conspicuous by absence. Within the area of observation the channel axis stability tends to suggest

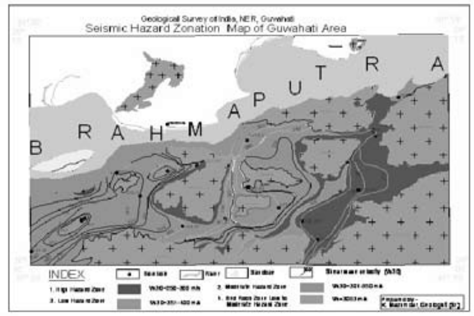
i) The depocentre axis of Brahmaputra basin did not shift significantly.
ii) The axis of fore deep down bulkling also did not shift significantly during the Holocene period.

Eismotectonic setting of guwahati and its suurounding

The seismotectonic setting of Guwahati Urban Region has to be viewed in relation to physiographic domains of NER. The principal tectono-physiographic domains of NER surrounding Guwahati are as below:

1. NNW- SSE trending Abor – Mishimi tectonic complex. (The syntaxial zone of Himalayan arc and Burmese arc).
2. Himalayan belt (collision zone) trending E-W to NE-SW.
3. NNE-SSW to N-S trending Assam –Yoma belt (Subduction zone) with high seismic zone of Sunda arc in the south.

4. Shillong plateau and Mikir massif marking plate boundary with Assam Valley
5. Barak valley, Bengal Basin and plate boundary zone of Tripura folded belt
6. Brahmaputra valley plain tectonic domain where Guwahati urban area lies.



The seismotectonic map of the area covering 200 Km radius around Guwahati on 1: 250,000 scale had been prepared for an area of 14,650 Sq. km, bounded by lat. 240 - 280 N and long. 98030'to94030'E. (Mazumdar, 2004) and analysis has been made in respect to study of Guwahati microzonation. (Fig: 3)

The compiled area around Guwahati comprises the Basement Gneissic Complex of Archean/ Pre Cambrian Origin (Apt /BGn) forming Meghalaya Plateu, Mikir Hills and parts of Sub-Himalaya foot Hills, followed by the cover sediments of the SubHimalaya, Peninsular and Indo Myanmar region belonging to Paleozoic-Mesozoic (Pz-Mz) and Paleogene – Recent (C1Cz 1-3) in antiquities. The cover sediments more or less deformed during the Himalayan fold-thrust movement in different times. Those occurring along the western flank of Indo Myanmar form the accretionary prism. The thickness of the cover sediments is variable with those occurring along the Sub-Himalayan foothills and Indo Myanmar show progressively increasing thickness towards north and east, respectively. It is also well reflected in the pattern of Bouguer anomaly contours. The basement and cover sediments are both dissected and displaced by the faults of various dimensions at various localities, some of which are seismotectonically active. The compiled rea is flanked by three prominent tectogenes viz. Himalayan and Indo-Myanmar mobile belts in the north and east, respectively and Meghalaya plateau including Mikir hills in the south and east. As such, it is identified with the faults of global scale like Main Central Thrust (MCT), Main Boundary Thrust (MBT), Main Foot Hill Thrust (MFT), Naga Thrust, Haflong Disang Thrust, Dauki Fault, Dhansiri-Kopili Fault, Dhubri/ Jamuna Fault, etc., some deep-seated faults of comparatively smaller scale but of enormous seismotectonic significance occur in the neighborhood of Guwahati Urban area. They include N-S, NE-SW, NW-SE trending active fault system of Garo hills eg. Chidran Fault, Dudhnai Fault, Kulsi Fault etc. which, it is believed, were the causative fault for the activation during the Great Assam Earthquake of 1897 (M=8.7). Recent studies by GSI have revealed their active nature through surficial geological investigation and MEQ monitoring. More or less same attribute has been obtained regarding the other faults also through available seismic data.

Basement contour map prepared on the basis of ONGC data, reveal an anomalous depth of occurrence of the basement in contiguous blocks indicating upliftment and subsidence. The Bouguer anomaly contours patterns of the area indicate a progressive increase in the thickness of the sedimentary wedge towards the Orogenic belts.

Seismic activity of NER is well known. Frequent occurrence of earthquakes in general, including few large and devastating ones in the recent past like that of 1897,(M 8.7), 1930 (M >7.0) and 1950 (M= 8.0) justifies proneness to seismic activity of the area. The meizoseismal area of the 1897 earthquake with its epicenter located in the West Garo Hills was as large as it could engulf the urban area of Guwahati (Oldham, 1899). The compiled seismic data has been taken from the various sources and a total of 581 Nos. epicenters have been plotted The area covered within 200Sq.km. radius, considering Guwahati as a centre has experienced 581 events having magnitude 3 and above from pre-historic to recent i.e. 1897 to 2000 (103 years). Epicentre plot of these earthquake events on 1:250,000 scale base map indicate that dominant magnitude class of Mb is 4-4.9 constituting 47.5 %, followed by Mb range of 5 – 5.9 constituting 14.3 %, Mb range of 3 – 3.9 constitute only 9.3 %. A total of 157 events did not have recorded magnitude (27 %). The larges earthquake events recorded within the radius of 100Km is Great Assam Earthquake (Mb 8.7). Four earthquake events of Mb 6-6.9 and four events of Mb 7-7.9 are located within 200 Km radius from the area of interest i.e Guwahati. Although the overall seismicity pattern of the area is scattered within the area, a clear cut demarcation in terms of tectonic domain can be visualized from the plot. In the north, parts of Bhutan and Arunachal Pradesh Himalaya are moderately active with large events usually concentrated towards north east around Bomdila. Most of the Himalayan events are shallow foci (0-40 Km), but, few events with focal depth 41 – 70 km also occur. Focal mechanism solution of events (No. 1,2,3,4 & 5) shown in the plate No. XII, occurring in the north of MBT, indicate either thrust type or strike slip mechanism of the faults. Three events of moderate magnitude located within the Brahmaputra valley tectonic fore deep area shows similar mechanism (No. 8, 9 & 21). In the south of Dauki fault, the zone of intersection of Dauki and Sylhet fault forms a major structural not characterized by occurrence of number of major and damaging earthquakes. Recently the earthquake of 8th May, 1977 recorded considerable damage around Karimganj. Fault plane mechanism of few events located south of Dauki Fault shows inconclusive solutions to define the exact style of slip or deformations. However solution No. 12 & 13 related to Sylhet fault indicates left lateral strike slip movement along NE nodal plane.

Record of Intensity:

The macroseismic study of few major events (Annexure- III) has revealed that the Guwahati area is very much prone to seismic damage for all high magnitude earthquakes located far away as well as for a low magnitude nearby events. The damage intensity in Guwahati area with reference to its distance from epicenters of the events are shown below:

Earthquake Events	Magnitude	Intensity Order (R.F scale)	Azimuth	Distance from Epicentre
Great Assam Earthquake,1897	8.7	X-XI	045	100 Km
Srimangal Earthquake, 1918	8.0	IV-V	170	150 Km
Dhuburi Earthquake, 1930		VIII-IX	250	180 Km
Assam Earthquake, 1950	8.3	VIII-IX	065	550 Km
Indo-Burma Earthquake, 1988	7.3	VI (MM)	110	750 Km
Indo Bangladesh Border Earthquake. May, 1977	5.3	-	160	-

For the purpose of seismic microzonation of Guwahati agglomeration the highest level of ground motion in the form of Intensity induced by near and far off events have been considered. This is only to get an approximate idea of the maximum level of ground motion in the form of intensity expected in Guwahati area and not the exact. The 1897 (8.7 Mb) event has been considered as scenario earthquake being the highest, which occur at 100 Km distance on S450W from Guwahati and originating from intra continental region (Shillong Plateau). According to Oldham 1899, Guwahati area falls in Isoseist XII (R.F), which subsequently re-evaluated by Narula et al. (1997) as Isoseismal zone XI on MSK scale and identified the source mechanism as thrust mechanism with single detachment surface unlike two detachment surface postulated by Gahulaut and Chander, 1992.

As we do not have recorded depth of focus of this event, for our purpose of seismic microzonation of Guwahati area we considered following two possibilities:

i) On the basis of intensity of damage XI on MSK scale and Magnitude 8.7
ii) On the basis of Intensity damage X on R.F scale (Boundary of epicentral tract (XI).

Considering the re-evaluated damage scenario by Narula et al. the depth of focus 'h' is calculated to be 28 Km, while, on the basis of Oldham's damage intensity X (R.F), depth of focus is evaluated to be 53 Km.

Thus the highest recorded damage intensity of X (R.F) has been for an event of 8.7 Mb and shallow focus origin at a distance of 100Km from Guwahati has been validated. However due to far off event (>200Km) will have considerable damage (of the order of VI & VII) at Guwahati, as seen from the 6th August, 1988 Earthquake located at 750 Km distance with magnitude 7.3 and intermediate depth of Focus (63 Km).

Landslide hazard zonation

The landslide hazard zonation map has been prepared on 1:50,000 and later enlarged to 1:25,000 scale (Plate No. XIII) for the purpose of the project. The hazard zonations have been prepared according to the total estimated hazard (TEH) of each facet by superposing the slope facet map successively one by one over all the thematic maps. The TEH of the facet is calculated after adding the values of land slide Hazard Evaluation factor (LHEF) of all nine geo – environmental parameters encompassing the particular facet. The Landslide Hazard Zonation map (Plate No. XIII) show only three categories of hazard zones Viz. Low Hazard Zones, Moderate Hazard Zones & High Hazard Zones.

The map of landslide Hazard Zonation would serve as the base map for planning of developmental activities for the need of vast growing population. The high hazard zones may be avoided for further developmental activities and moderate hazard zones should be used judiciously by using engineering protection measures. It is to be noted that in the recent past most of the landslides in the area occur within the scientifically identified moderate hazard zones. Obviously these landslides have been generated due to anthropogenic causes and does not necessarily represent or classified to be high hazard zones.

Subsurface Exploration by Drilling for Geotechnical Properties of Sediment

The physical properties of sub surface soil are considered to be the most significant parameter, which plays key role in disaster during earthquake wave motion. In order to study the geotechnical properties of soils and rocks of Guwahati Urban area different bore hole data generated by private as well as government organizations in connection with design of buildings have been collected from GMDA, GMC through AMTRON during the course of study of seismic microzonation of Guwahati Urban area. The study of the data revealed that the litho logy of the bore hole as well as different properties evaluated by different Organizations are not in conformity with the ISI specifications. Although there were many other unpublished data, yet, due to incoherency of procedure adopted during exploration, acquisition and analytical procedure of samples and limitation of procedural approach for in situ SPT test for 'N' value determination, these data could not be utilized for our project. Hence as a part of preliminary data acquisition an exploration programme of 30 bore holes (BH) were planned for Guwahati Urban area, out of which 5 bore holes were planned down to the depth of + 5.0 meter in bed rock level and remaining 25 bore holes up to 30 meter depth as considered elsewhere in other countries. Drilling and in Situ Standard Penetration Test (SPT) was done by the author himself in 80 % of the boreholes. During the drilling and insitu test various field limitations were met with which had to be tackled carefully, particularly in making correct decision at the time SPT Test, logging of litho logy as well as sampling.

Limitations

i) In the engineering practice, depth of acquisition of 'N" value parameter usually varies from 6.0 to 15.0 meter depth.

(ii) Blow counts up to maximum of 50 numbers particularly for engineering structures (Foundation level). But in this project of Seismic Microzonation, if blow counts limited up to 50 (beyond which it was considered as refusal or sufficient for engineering structures) is considered, then, the actual properties (density, void ratio, moisture content, etc) of the sediments would be misled. Hence, we have considered blow count till actual refusal rather than considering refusal at maximum 50 blows.

ii) Lithologs are not co relatable with actual litho logical sections probably due to logging done by non-geologist or inexperienced persons. Further, logging was done on the drill sludge and not by core drilling.

In this context it is to mention that collection of Undisturbed (U/D) samples & logging was to be done very carefully, because during drilling collapse material may misled and at many a times when the job was handed over to inexperienced persons we faced / encountered this problem.

Methodology adopted:

1. Unlike others, drilling done by manual conventional method, we have carried out drilling by drilling machine (Jodhpur Rock Drill and Max) by experienced drillers of the department under the personal guidance of the author. Drilling was carried out in NX size hole, as per ISI specifications vide Code No: ISI-2131 (1963). Maximum dry drilling was carried out under normal load. Undisturbed samples were collected in NX drilling Casing Sampler for each 1.0 m section leaving SPT sections, where SPT sampler was used for both blow counts and U/D sample collection. As per International practice done else where, we have considered the depth of exploration up to 30 meter, as the upper 30 meter thick sediment horizon plays vital role in dissipation of seismic surface wave velocity (Vs30).
2. Unlike others, strictly, dry drilling has been done so as to document the exact litho log of the borehole section. Standard penetration has been done at one-meter interval and each core drilling section has been maintained at 0.50 m.
3. Out of the planned 30 bore holes only 25 bore holes could be drilled i.e. of the total five deep bore holes only one hole could be drilled up to bed rock depth. The detail summarize litholog of each bore hole have been given in the following tables:

From the detail litho log of boreholes following observations and interpretations are made.

1. In Deepar bill region i.e. on the western part of Guwahati, the top 10 m is represented by silty clay, clayey silt or sandy silty clay with ubiquitous litho-facies variations, while towards bottom i.e. invariably below 10 meter depth, fine to medium grained sand occasionally with intermittent silty clay and sand facies constitute the litho-package up to 30 meter.
2. Although the characteristic geotechnical properties of the sediment are classified to be liquefiable in nature, the depth of occurrence of the same does not indicate much risk potential zone of liquefaction unless and until high energy shaking for longer time period occur.

3. In the eastern portion of Guwahati more precisely in the Taper Bill region liquefiable sediments occur at shallow depth, which is a point of concern from liquefaction potential point of view, except eastern part of the bill. Besides, zones between Ganeshgur i- Zoo Road – Chandmari also indicate moderately risk zone of liquefaction. However, due to limited number of boreholes, the interpretations may be used with reservation. With the addition of more data on closer bore holes, risk potential zones could be classified in detail.. Due to absence of bore holes in the area between Silpukhuri- Uzanbazar - Panbazar and Bharalumukh we could not comment on such liquefaction characteristics of the area.

Geotechnical Properties of the Sediments of Guwahati Urban Area

The various geotechnical properties of soils and rocks of Guwahati Urban area have been determined during the course of studies.

The analytical results have been utilized for inferences in this area.

Two rock samples collected from bore hole (BH- 2) have been subjected to Vp and Vs evaluation in Geophysical Laboratory of Central Geophysics Division (CGD), CHQ, GSI, Kolkata and results are used in analysis.

The S-wave velocity determined for moderately weathered rock and fresh rock samples have been averaged out for calculation of shear wave velocity of granite gneisses and used the same for other practical use in seismic microzonation studies.

N – Value Determination by Standard Penetration Test (SPT)

As described under the head “Methodology” the Standard Penetration Test (SPT) was carried out in all the boreholes to derive ‘N’ Values of soil mass. Each test was carried out at 1.0m interval and visual textural identification of the soils was made. While carrying out test, every day ground water level was recorded two times. The observed ‘N’ values have been corrected as peer ISI 2131, 1963 for water level, Over burden pressure and textural conditions. During the SPT test unlike normal procedure in engineering practice, in our project we have considered actual refusal condition to arrive at actual density, rather than, considering required density at ’50 N Blows”.

From the SPT test it has been observed that for a homogeneous sequence of soil column, the N value has an increasing trend towards depth in a single bore hole sequence, other wise it varies according to the lithological nature and condition. For example, in Bore hole No. 1 in the upper clay horizon from 1.5 m to 6.0 m N- Value varies from 12 –32, while in bottom medium to fine grained sand it varies from 21 to 57 and then in coarse grained oxidized sand it ranges up to 102. It has been observed that the N – value strictly depend on lithological variation, density, void ratio, besides overburden pressure and saturation condition of the sediment (Water table) As seen from the Bore hole No. 4 that in top oxidized sticky clayey soils N-Value varies from 20 to 29, while bottom buff sandy clay it shows 19 to 20 and for sand it ranges from 42 to 93. The highest N value of the order of 168 is observed in borehole No 8, at a depth of 17.50 to a7.95 m. Here the lithology is characterized by 91% sand & 9% silt and having very low moisture content being only 11.68%. The density of the soil varies from 1.91 to 2.00 and void ratio maximum 1.73.

The perusal of N value variation revealed that in general N-value increases with depth in homogeneous sequence, which, also depend on saturation condition, density, over burden pressure etc. In case of inhomoginity it does not follow the rule rather it is observed that it varies as per lithology in order of saturated soil/ overburden clay, silty clay, clayey silt, clayey sand, silty clayey sand, sands, sands with grit and pebble.

In almost all the boreholes, the 'N' value test were confined to the horizons below water table except in a few where, water table was encountered at 0.3 to 1.5 meter. It is noted that the upper 0-3m horizon, the N value varies from 12-47, except in one bore hole i.e. in BH 11, where the sediments are oxidized silty sandy clay as per lab analysis or it may be that test was erroneous. In the layer 3-6 m, it varies from 16-63 except in BH. No. 2, where it varies from 61-96 and the sediments comprises highly oxidized sandy clayey silt. In the layer of 6-9 m, it ranges from 16-57, except in borehole No. 10 where it varies from 40 to 70. In the 9-12 m layer it varies from 10-59, in 12-15 m horizon it varies from 10 – 59 except in Bh. No. 1, 8 & 15 where it ranges from 34-115, 38-88, and 51-58 respectively. The layer between 15 m and 20 m it ranges from 13 – 88 with one anomaly in Bh. No 8 where it ranges from 23 – 168. Lastly, between 20 and 30 m it varies from 14 – 86 with exception in Bh. No. 1 (29-102) and Bh. No.8 (42-130). It is observed that wherever high 'N' values occur, the horizon is under the influence of full saturation condition (Ground water).

Liquefaction Susceptibile Horizons of the Area

As the various soil characteristic parameters contribute to liquefaction susceptibility, an attempt has been made to analyze the soil properties, like granulometric curve, density, cohesion, textural classification of soils, plastic limits, liquid limits, plasticity index etc. On the basis of 'Yes' or 'No' characterization of above attributes the sediments have been classified into liquefiable or non-liquefiable.

Further, relative density and confining pressure with ground water level condition have been considered while identifying liquefaction susceptibility of the sediments and prepared the liquefaction susceptible map of the area with limited bore hole data. It has been observed that the area around Azara, Airport, Dharapur Lankeshwar, Sanskrit College, Maligaon Railway colony, Garhchuk, Ahomgaon and South of Bashishtha Chariali area show liquefiable horizons at shallow depth, which under the influence of groundwater shaking during earthquake may cause disaster and need to consider for designing the buildings. Further lithology around south of Hengerabari, Zoo road (Ganeshguri), the Liquefaction potentiality scenario of the area may change with addition of closer borehole data. The perusal of past earthquake intensity maps indicate that during 1897 the area has suffered moderate liquefaction hazards with few ground failure in Guwahati area.

Shear Wave Velocity Evaluation

Shear wave velocity (Vs) in top near surface geological formations plays an important role in controlling ground motions during an earthquake. In Guwahati Urban area, the Quaternary alluvium occupies the valley surface and overlying the Pre Cambrian Granite and Granite Gneissic basements. This alluvial column has both spatial and vertical variation from 0 to 300 m depth and from east to west. In absence of any direct measured shear wave velocity, we have used "N' value data of subsurface soil column at different depth usually at 1.0 m interval for entire drilled depth of 30 meter. The observed 'N' valued are corrected and designated as corrected 'N' value ('NCr"). The textural classification of soils have been done both at site {Field study) and on the basis of mechanical analysis, on the basis of which the soil of the area have been classified into four major classes with intercalated variation of the sediments at times. And the same classification of soils has been utilized in our shear wave velocity evaluation at each site. Besides, the depth to basement or thickness of the sedimentary cover overlying, have been used from the basement contour map prepared for calculation of other parameters for the microzonation exercise.

Following the relationship of 'N' value and shear wave velocity (Fumal & Tinsley 1985) for cohesive and cohesion less soils, we have evaluated shear wave velocity for classified soils of the area.

In absence of any relevant direct shear wave velocity measurement from Guwahati Urban are , such standard correlation could not be developed for our area. For obvious reason we are constrained to use the above mentioned relations to assess the shear wave velocity at different sites of Guwahati area.

The shear wave velocity has also been evaluated by different relationships like Tonouchi et.al. (1993), Kamil & Kayabali (1996) having very good correlation coefficient.

We have left no option out for evaluation of Vs for Guwahati area by all the above relations and judiciously averaged out for above mentioned Shear wave velocity at 1.0 m interval and finally averaged out the shear wave velocity for different layers i.e
0 – 3, 3- 6, 6- 9, 9- 12, 12- 15, 15- 20, and 20 – 30 m.

Limitation of shear wave velocity (Vs) and data interpretation

It is known that lower shear wave velocities results in higher amplitude of ground motion i.e. the area having low Vs are likely to experience strong shaking than the area having high Vs. Further towards basin margin Vs is lower than the central part of the basin. However, we have following limitations in our interpretation.

i). Heterogeneity of the topography of the area i.e. inselbergs, basins, valley plain, & reclaimed land etc introduces ambiguity (ii) Spacing of bore holes is not uniform and (iii) number of bore holes are limited.

Under such circumstances the interpretations made from these limited bore holes will give a general idea and likely to change with closer density of data. But never the least, the interpretations will guide in classifying the zones of different hazard levels.

The average Vs varies from minimum of 199.79 m/sec at 0-3m layer in Pandu to maximum of 635.58 m/sec in 0-24 m section near Maligaon Rly. H.Q. The study of vertical Vs variation reveal that in 0-3 m section Vs3 varies from maximum of 363.14 m/sec in Azara area to minimum of 209.87 m/sec in airport area. Vs5 varies from maxm of 376.77 m/sec in Azara area to minimum of 222.66 m/sec in Hengerabari area, Vs10 ranges from maxm of 365.90 m/s Azara to minimum of 228.28 m/sec in Hengerabari area.Vs15 varies from 371.60 m/sec Lokhra to 238.61 m/sec Dharapur, Vs20 varies from 363.21 m/secLokhra area to 261.24 m/sec in Dharapur area, VS25 varies from 408.07 m/sec in Maligaon to 271.71 m/sec in Birkuchi area, finally VS30 ranges from minimum of 269.51 m/sec in Birkuchi area and maximum of 406.59 m/sec in Maligaon area..

The lateral variation of Vs30 indicate that within the Deepar Bill regime towards basin margin Vs30 reduces i.e. towards hill margin probably due to less alluvial cover. Similarly in Taper Bill regime towards edge of the hill the Vs is comparatively lower than the central part of the basin, which suggest that towards edge, the basin margin effect may play vital role in cognizance with higher ground failure susceptible zones. Alternatively, the area around NE of Garchuk, Datalpara, maligaon the shear wave velocity is found to be high.

On the basis of lithology, N- value and Shear wave velocity (Vs30) of the sediments, the sites have been classified into microzones depending on Vs ranging from 250 – 300, (Class I site), Vs 300 – 350 (Class II site) and Vs 350 – 400 and above (Class III). Due to absence of closer bore hole data, the classification of site response zones have been constrained by shear wave velocity contour map prepared by available data for different layers for the study area. (Fig:- 4) The predominant frequeny, Liquefaction potential zones, site amplifications factors are also taken into cognizance while classifying microzones.

Discussion, Conclussion and Recommendations

- The study of seismic microzonation of Guwahati Urban area has been based purely on compilation of existing data for base geological and geomorphological inputs and shallow subsurface geology has been constructed through subsurface exploration of bore holes and existing geophysical data. These base maps have been earlier submitted to DST for use in microzonation project on Guwahati (2004)
- The present exercise has culminated in the preparation of shear wave velocity, predominant frequency and liquefaction hazard maps of Guwahati Urban area.
- The results and analysis has been done on the basis of limited borehole, thus having its limitation in interpretation. However, an effort of such preliminary nature is fairly appreciable in absence of directly measured shear wave velocity of the area. When drill whole data are sparse, some extrapolation based on surface geology, geomorphology, sub surface geophysical

interpretations and borehole data of other agencies have been considered to bridge the gap in the map.

- Geomorphologically, the Guwahati urban area represents (i) denuded hilly area in the south and characterized by rocks of high shear wave velocity (Vs 3800 m/s +). However the top 10 to 15 meter residual soil cover has low shear wave velocity (not identified) and may cause impedance contrast (ii) Isolated hillocks protruded through thick alluvium, (iii) flat valley filled alluvium in the centre (moderate shear wave velocity Vs 300 – 400 m/s) and (iv) low lying swampy depressions called 'bil' in local parlance which is filled with clayey silty sand. The urban area spreads over both alluvial plain and hillock ranging in elevation from 45m to 150 m m. s. l. Alluvial plain area lies between 45 and 70 m. height and above it the pediment zone followed by plateau area lying between 70 and 300m a. m. s. l. The low lying bills and ponds are structurally controlled and encroached by human for habitation and resulting into decrease in open space and ecological imbalance.
- Prominent litho units of the area belong to two different ages ranging from Pre-Cambrian to Recent. They are composed of granite, granite gneiss, migmatites etc. With thick sedimentary cover of quaternary and recent. The occurrence of carbonaceous material (Lignitic) in south of Kalapahar, Bore hole No. 12) is highly significant in context to the stratigraphy of the area which need to study indetail. Obviously the area is likely to develope high impedance contrast with varied amplification and seismic rigidity.
- Depending upon the variation in composition and texture of rocks, structural disposition, slope and relief, inselbergs / exotic blocks, terraces can be divided into to subunits viz. low relief hummocky terrain with deep weathering and distinct intervening valley flats and high relief hills having definite crest / ridge line, steep slopes, 'V' shaped valleys without alluvial fills and comparatively thin veneer of weathered mantle. The extents of land use pattern on these two units are markedly different.
- Obviously the inselbergs having high relief with steep slopes and hanging boulders / wedges on the slopes would cause high degree of hazards although lithologically the area is low hazard zones. Such areas are marked around north and south of Maligaon particularly around slopes of Nilachal and Fatasil hills. The occurrences of past landslides (not earthquake induced) from these areas validate this i. e. moderate to high risk zones within the technically defined low to moderate risk zones. Under such critical analysis the area with slopes greater than 400 and having development without judicious protection measures against hazards would be classed as moderate risk zones.(i.e one level higher than actual)
- The qualitative nature of the results not withstanding, could not be validated for effect of any past earthquake from the whole area. However, the present exercise could not cover large area due to lack of data from such area. The shear wave velocities estimated from Hatigarh-Bamunimaidam area (BH- 16, Vs 288 m/s) is validated for shear wave when correlated with

observed damage pattern during 6th August, 1988 earthquake (Mb-7.3). The damage has caused due to high impedance contrast and shallow bedrock level in this locality, besides poor construction material and aseismic design of the buildings.

- The shear wave velocities (Vs30) in eastern part of Maligaon railway colony have been estimated to be of highest order of 406.89 m/s indicating that this area is among the safest soil covered localities.(Low hazard risk zone)
- Comparatively the western part of Guwahati urban area, which mostly falls under 'Deepar bil' regime show relatively higher shear wave velocity ranging from 290.13 to 406 m/s. The North eastern part of 'Deepar bil' particularly around Maligaon, Sadilapur, Jalukbari and Pandu area show relatively higher shear wave velocity varying between 295.88 and 406.59 m/s,. In the central part of Guwahati i.e. around Garchuk, Katabari, Datalpara, Ahomgaon, the shear wave velocity is found to be high ranging from 303.37 to 361.87 m/s. while in the eastern part of the urban area around, Bashistha, Khanapara, Panjabari and Noonmati area mostly falling under 'Taper bil' regime, the shear wave velocity varies from 282.29 to 340.56 m/s.
- It is observed that towards 'small basin' edges (margins) shear wave velocity is lower than the central part of the basin suggesting comparatively higher risk zone than the central part of the basins, this is mainly due to decrease in basement depth resulting into high impedance contrast.
- In the central part around Ahomgaon and along the eastern edge of the Fatasil Hill the shear wave velocity contours show clustering which is due to a fault passing through this area and sudden change in basement depth (25m to 150 m) within a short distance.
- The shear wave velocity (Vs30) contours derived from the different bore hole sites have been classified into four ranges viz. High Hazard Zone (Vs30 250-300 m/sec), Moderate Hazard Zones (Vs30, 301-350 m/sec), Low Hazard Zones (Vs30, 350-400 m/sec) for the soft sediment horizons i.e. in alluvial zones and moderate to low hazard hilly terrain having high Vs (>3083 m/sec) for the hard rock zones. On the basis of above classification the shear wave velocity risk zones due to earthquake have been demarcated and shear wave velocity map of the area has been prepared.
- In the high velocity zones namely in the hard rock terrains, risk may not be due to ground amplification rather the hill slopes and hanging boulders may cause landslide hazard risk. The same has been analyzed from landslide hazard zonation map prepared and three landslide hazard zones have been evaluated. Although there is no record of earthquake induced landslides in the study area the same can not be ruled out if near sources earthquake occur within periphery of 100 km as that of 1897. Because the anthropogenic influence has changed the geomorphological scenario of the area like that of generation of steep slopes, leaving hanging and floating boulders along the steep slopes in the area. Obviously the moderately hazard zones identified from the landslide hazard zonation studies may behave as high risk zone as evident from the recent landslide incidences (2004-2008) in Guwahati area.

- The Predominant Frequency map has been prepared by assuming a two layered subsurface configuration i.e. soft sedimentary layers overlying the hard basement rock and horizontally disposed one dimensional medium. However with the addition of accurate close spaced data may help in preparing much constrained predominant frequency maps.
- On the basis of SPT data, mechanical properties of subsurface soils and ground water depth, the liquefiable horizons (Liquefaction Susceptibility) in the south of the study area have been mapped. This map signifies that at a particular site, the chances of liquefaction likely to occur are relatively more because either the ground water condition and liquefaction susceptibility of the near surface material are more favorable and / or recurrence interval of the optimum strong motion there is less.
- It has been observed that the area around Azara, Airport, Dharapur, Lankeswar, Sanskrit College, Maligaon Railway colony, Garhchuk, Ahomgaon and south of Bashistha Chariali are highly liquefaction potential zone, while around east of Guwahati particularly around Sixmile, Panjabari, Narengi and south of Kalapahar area, liquefaction potentiality is low. However, around Bamunimaidam, Ganeshguri, Hengerabari area the liquefaction potentiality is moderate and depends on ground water level fluctuation.
- The result of this study slightly differ from that of other studies as because we have considered the actual refusal to penetration (N Value) parameters and hence need to be compared with closely spaced site specific response studies and direct shear wave velocity measurements at close interval.
- This kind of microzonation exercise may be of immense help to all the agencies or individuals responsible for developmental activities in an area or by maintaining the old structure. However it is suggested that site specific data may be used for design and construction as the interpretation made in this report are based on limited data base.
- In the light of the present study, the concerned authorities are suggested to make use of the findings in the design and construction of buildings in the Guwahati urban area and make a judicious plane for disaster management before knocking the disaster. It is also suggested to make use of the findings and bring into the knowledge about any deficiency while using the findings for further improvement

The Great Assam Earthquake of 1897 - Valuable Lessons Learnt

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Abstract : An attempt has been made in this paper to study the social, economic and scientific impacts and other related disaster mitigation aspects with many valuable lessons learnt from this tragic event of the Great Assam Earthquake of June 12th 1897 which has cost immense lost to both human life and property. The works of Sir R.D. Oldham the then Director of the Geological Survey of India, who personally studied its effects, directed and published an extensive, well illustrated monograph of his observations has been much cited by succeeding generations of Seismologists. From the various aspects of the disaster pertaining to the 1897 earthquake, numerable lessons are learnt for preparing and emphasizing the importance of minimizing the losses and focus on the disaster mitigation process. In this paper, more stress for earthquake disaster management is made with regards to Shillong city.

Keywords: *Earthquake, magnitude, intensity, mitigation*

Introduction

The Earthquake of June 12th 1897 holds a special place in the history of Seismology. It is one of the biggest earthquakes of recorded history and this event laid the foundation of Seismology in India. The epicentre of the earthquake was near Mendipathar, Meghalaya, and the magnitude of the earthquake was later established to be 8.7 on the Richter Scale. Sir R.D. Oldham who personally studied its effects published a monograph which is one of the most valuable source books in

Seismology. His name has been associated with much pioneering work during the years when Seismology was passing from the pre-instrumental period into the era of the seismograph.

The1897 earthquake was particularly destructive, and devastated a huge region of Northeastern India. Observations that heavy objects such as large boulders had been thrown of the ground were the first documented evidence that earthquake ground motions can exceed the force of gravity.

An early description of the earthquake appeared in Nature on 17 June 1897. A note from Thomas Heath of the Royal Observatory, Edinburgh, on violent oscillations of a pendulum at the observatory caused by the earthquake, was reported. Further evidence from pendulum records at the Royal Geodetic Observatory of Rocca di Papa, Rome described by Professor P.Blaserna, was reported later. The cylindrical seismometer at Shillong indicated that the shock consisted of an oscillation of 7.4 inches at the rate of 60 times a minute.

This earthquake is not only one of the world's largest but also one of which a detailed study was undertaken. The earthquake occurred at about 5:15 PM local time and was responsible for 1542 deaths. Almost total destruction of all brick and stone buildings in all the principal towns of Assam including, Sylhet, Goalpara, Dhubri, Guwahati and Tura was reported. The region of greatest intensity embraced about 30,000 square miles. Within this area, there was practically total destruction of all brick and stone buildings. Within this area of maximum destruction, Oldham outlined a hat- shaped area of about 11,000 square miles in which there were dislocations of the ground, changes in position indicated by surveys and vast numbers of aftershocks (Fig1). The intensity of the shock within the epicentral tract was so large that visible waves were seen at a number of places at Shillong, Nalban and Magaldai. Estimates of the horizontal ground acceleration at Shillong and Cherrapunjee were 4200mm^2/sec and 3000 mm^2/sec respectively.

Most of the inhabitants of the epicentral region were out of doors at 5:15 PM, so the death toll was comparatively small. Many of those killed were crushed by landslips. Serious damage to buildings occurred in an area of about 150,000 square miles. The total area in which the earthquake was felt was estimated by Davison as 1,750,000 square miles. The most violent part of the shock was probably a little less than one minute, with a total duration of perhaps three minutes. People were thrown to the ground and mauled by the shock: some were thus injured. Near Nongstoin a splinter of granite 3 feet by 1 foot was thrown 8.5 feet up. Many houses were sunk into the soft soil until only their roofs were visible. Visible waves on the ground were noted widely. Oldham has estimated the size of the waves as about 30 feet by 1 foot high. Some 50 miles east of the Chedrang fault near the town of Bordwar, a fracture of the earth and rock broke open for 7 miles but showed no displacement. Landslide and destruction of timber near this fracture were great. Landslides were very common and disastrous in the epicentral region. The hills were stripped bare of their forest covering by slides for some 20 miles. Fissures in the alluvium were common over an area of 400 miles by 350 miles. Level rice fields were left in low swells after the passage of the earthquake waves. Telegraph poles in the alluvium were displaced as much as 15 feet to one side of the general line. Earthquake fountains ejected sand to such an extent as to hinder farmers in later cultivation.

Shillong was rebuilt after the earthquake. Now its population has increased substantially. In 1953 it became the head quarters of the seismological service in India till 1957 and now it has an excellent station. (Richter 1958)

Observations

A few of the eyewitnesses' accounts reported by Oldham for Shillong, the administrative centre of Assam at that time are given below.

"At about quarter past five in the afternoon of 12th June 1897, there burst on the western portion of Assam an earthquake which, for violence and extent, had not been surpassed by any of which we have historic record. Lasting for about two and a half minutes, it had not ceased at Shillong before an area of 150,000 square miles had been laid in ruins, all means of communication interrupted, the hills rent and cast down in landslips and the plains fissured and riddled with vents, from which sand and water poured out in most astounding quantities; and ten minutes had not elapsed from the time when Shillong was laid to ruins before about one and three quarter millions of square miles had felt shock which was everywhere recognised as one quite out of common." (Oldham, 1899).

On that day Mr and Mrs A.E.Shuttleworth were sitting on the verandah of the Chatgari rest house waiting for a slight shower to stop. At 5-13 PM, they were suddenly startled by a very vivid flash of lightning followed by a tremendous crack of thunder. At the same time the bungalow began to tremble slightly. As the trembling motion began to increase, Mr Shuttleworth cried out that it was an earthquake. They then saw the earth all round heaving in a most frightful manner. The earth resemble waves coming from opposite directions and meeting in a great heap and then falling back: each time the waves seemed to fall back the ground opened slightly, and each time they met, water and sand were thrown to a height of about 18 inches or so. The shock was so strong to knock over a couple of elephants they had in the camp with them. His horse too in the stable was knocked off his legs and his dogs could not stand up in the verandah of the bungalow.

"I was out for a walk at the time. At 5-15 PM… a deep rumbling sound, like near thunder, commenced…followed immediately by the shock…The ground began to rock violently, and in a few seconds it was impossible to stand upright, and I had to sit down suddenly on the road…The feeling was as if the ground was being violently jerked backwards and forwards very rapidly, every third or forth jerk being greater scope than the immediate ones. The surface of the ground vibrated visibly in every direction, as if it was made of soft jelly: and long cracks appeared at once along the road. The school building, which was in sight, began to shake at the first shock, and large slabs of plaster fell from the walls at once. A few moments afterwards the whole building was lying bent and broken on the ground. A pink cloud of plaster and dust was seen hanging over every house in Shillong at the end of the shock. My impression at the end of the shock was that its duration was certainly under one minute…subsequent tremors lasted some time…The whole of the damage done was completed in the first 10 or 15 seconds…"(Oldham, 1899).

A similar description, like that of Sir R.D.Oldham, of the great earthquake is given in the book "From Residency To Raj Bhavan – History of the Shillong Government House" by Prof. Imdad Hussain, retired Professor of History of NEHU, Shillong. He writes that, at the time of the 1897 earthquake, Sir Henry Cotton was the Chief Commissioner and was occupying the Residency. On 12th of June, Shillong was preparing to celebrate the Golden Jubilee of Queen Victoria and Lady Cotton had just arrived from England for the occasion. Quoting from the above book, the description of the earthquake in Shillong:

"Then at about 5:10 in the evening there was a rumbling underground noise followed by a light tremor. This was followed within seconds by a shock of such intensity that all masonry buildings were instantly leveled to the ground. The earth trembled so violently that the newly built Catholic Church and the houses of the priests and nuns on Priests Hill south of the Residency collapsed and the church bell began to ring on its own, as if warning everyone. The four or five minutes of that terrifying noise and shocks seemed an eternity. It became difficult to walk and those who had gone to the woods fell, vainly trying to keep themselves upright by clinging from tree to tree. The tennis courts opened up below the feet of the players and the golfers lay prostrate on the Links."

Extent of Area affected

The magnitude of the 1897 earthquake was 8.7 and "an area of 150,000 square miles had been laid in ruins" in modern day Meghalaya and Assam, including the whole of Shillong. The area of present day Greater Shillong Planning Area is about 174 square kilometers (67 square miles) and Meghalaya has an area of 22,429 sq.km. (8,657.6 sq. miles). These figures give us an idea of the extent of area which may be affected by such large earthquakes. All these Northeastern States are in Seismic Zone V, the highest seismic prone areas on the Seismic Map of India. Parts of Gujarat are in the same zone, and the destruction caused by the Bhuj earthquake of 2001 is still fresh in our minds.

Effects of the earthquake

The great earthquake of 1897 was "an earthquake which, for violence and extent, had not been surpassed by any of which we have historic record", and, although the epicentre was near Mendipathar, ground waves were seen even in Shillong. It was so violent that people were thrown to the ground, even injuring some. Some domesticated elephants and horses were also knocked down by the shock and dogs could not stand up on the verandah of cottages. On the slopes of the Khasi Hills, embedded boulders were thrown out from their original places and projected to other places. The intensity of the earthquake was such that all were "laid to ruins" in the affected area; all houses made of brick and stone were almost totally destroyed in all the principal towns like Shillong, Tura, Guwahati, Goalpara, Dhubri, and Sylhet. Many houses sunk into soft soil, due to liquefaction of the soil during the earthquake, with only the roof visible. In the Garo Hills, although the damage was extensive, yet the damage and loss of lives were less than in the Khasi Hills because of absence of stone masonry houses. The death toll in the Garo Hills was only 27 while in the Khasi Hills it was over 900.

Landslides occurred on a massive scale, stripping the hills bare of forest for almost 30 kilometres. Road, rail, and other means of communication were completely disrupted, the ground was fissured and sand vents appeared. In fact the geography, in the epicentral tract, was changed. Many streams changed their courses, even the bed of the Brahmaputra was affected, resulting in unprecedented floods during the same year. There was vertical movement of about 10 metres on either side of the Chedrang fault running north –south through Mendipathar in Garo Hills. Considerable portion of the bed of the River Krishnai (Damring) subsided and a lake was also formed. This lake is called Dekachang and is15km long and 1.5km wide.

Vulnerability

Meghalaya is geologically bounded by some active faults/thrusts – on the North by the Brahmaputra Fault, on the South by the Dawki Fault, in the East there is the Kopili Fault, while in the West we have the Jamuna Fault. There are other sub-faults and thrusts also. Besides the great earthquake of 1897, Meghalaya experienced two other large earthquakes, both of magnitude 7.1; one in 1923 in West Khasi Hills and the other occurred in the year 1930 in the West Garo Hills. Both these earthquakes caused widespread damage.

The vulnerability and the risk of a disaster in an earthquake has increased manifold due to the changing topography, rapid development, as well as environmental degradation. In 1853, the combined population of Khyriem 'province' and Cherra was 32,635. In 1901, the whole of Khasi and Jaintia Hills had a population of 2,02,250 and Garo Hills had a population of 1,38,274. The population of Greater Shillong Planning Area, assessed from the 2001 Census, is itself 3,31,373. The growth of population and the increased building activity have made the Urban Centres very vulnerable to disasters with very high risk of destruction in a large earthquake. Within the Shillong Municipalty, Ward No.14 and Ward No.20, that is, Jaiaw Shyiap, Lumpyllun& Jaiaw Pdeng, and Upper Mawprem are the most densely populated with over 57,000 persons per sq. km. and over 74,000 persons per sq km respectively. The density of households is also highest in these Wards, the figures being over 3000 households per sq km. If an earthquake similar to the 1897 earthquake were to occur today, the loss of human lives would be many times more than the figure of 1897, for the entire affected area.

Most of the people were outdoors when the earthquake of 1897 occurred. Therefore, the casualty was less. Most of the people who lost their lives in the 1897 earthquake were buried in landslides. However, the Latur earthquake occurred at night and the loss was much more, almost all of them were buried in the debris of collapsed stone masonry houses, with stone slab roofs.

In addition to the earthquake hazard, the risk of disasters due to other hazards like fire, landslides, flood, cyclones etc, including collapse of man-made structures, have also increased in the Urban Centres. Some of these may also be initiated by an earthquake.

The task of building up our preparedness to meet any kind of disaster is huge and the degree of readiness of our response which is to be achieved is clear.

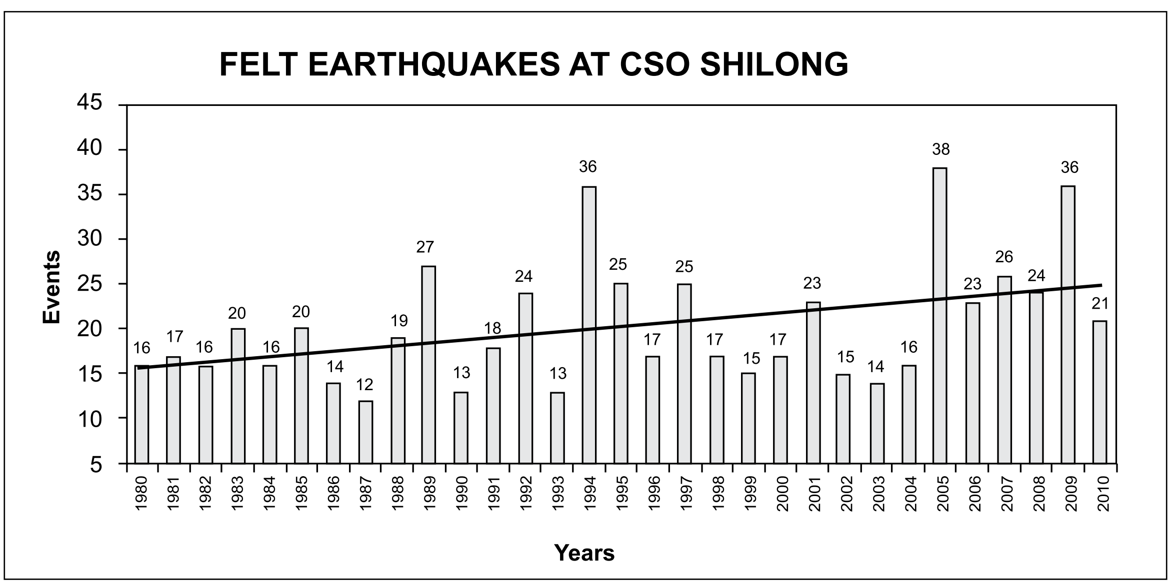
Early warning

"There was a rumbling underground noise followed by a light tremor". Sir Henry Cotton later recalled the deafening noise of the earthquake "blended with the cries of terror" which rose all around. (Cotton-Indian and Home Memoirs).

The children of Bhuj, parading outside on the 26th of January, 2001, did not recognize the crackling, rumbling, deafening noise of the earthquake on that fateful day. They thought it was a bomb blast and, therefore, they ran inside the schools and unfortunately the buildings collapsed.

Animal behaviour

Sir Cotton and his wife had just got up on to a buggy when the first severe tremors were felt. The frightened horse bolted "like an arrow from a bow" and galloped towards the main gate. Sir Cotton somehow managed, "more by luck than skill", to stop the carriage and both he and his wife had a providential escape. "As I leapt from the trap, I looked back to where Government House had been, and saw nothing but a great pillar of red dust from earth to heaven". (Cotton-Indian and Home Memoirs).



Destruction in Shillong

The Government House was then a building made of stone masonry, with wooden roof truss and corrugated iron roof sheeting (Photo 1), which was completely destroyed in that earthquake of 1897 (Photo 2). Similarly, the All Saints Church, which was built in a semi-gothic style in stone masonry with buttresses (Photo 3), also completely collapsed (Photo 4). The Secretariat and other government buildings were also completely destroyed. In fact, as said earlier, all buildings made of stone and brick failed miserably during that earthquake of 1897.

Photographs 1 to 4 are taken from the book "From Residency to Raj Bhavan, History of the Shillong Government House" by Imdad Hussain,2005, Regency Publications, New Delhi.

Mitigation

As per the Census of Housing, GOI, 2001, 15.4% of the houses in Meghalaya are still made of stone or bricks. One such house in Sohra is shown Photo 5, which appears very vulnerable to earthquakes. In addition to the 1897 earthquake, we have seen in the 1991 Uttarkashi earthquake, in the 1993 Latur earthquake and again in the 2005 Kashmir earthquake, the devastation caused and the number of human lives lost due to collapse of dwellings made of stone. There is an urgent need of retrofitting these stone masonry houses to withstand the impending earthquakes and to mitigate its effects and to save human lives. Adopting alternate lighter material of construction, like the bamboo, is another option.

Assam-Type houses

The Government House and other buildings were rebuilt adopting timber for the posts, framework and roof supporting structure, with ekra or reed walls covered by lime plaster (Photo 6 & 7). These are light, resilient structures and can withstand the forces(Vertical & Horizontal) of an earthquake very well, as has been demonstrated by these buildings since the 1897 earthquake. The present day Deputy Commissioner's bungalow at Tura (Photo 8), withstood the earthquake of 1897, and a very old cottage in Laban, Shillong, part of which withstood the same earthquake (Photo 9), are both timber structures, and bare testimony to their efficacy. Of course, regular maintenance is required and cross members in walls and roof trusses may be added to increase their resistance to earthquake forces.

RCC buildings and retrofitting

There were no reinforced cement concrete (RCC) buildings during that 1897 earthquake, but RCC buildings have withstood the 6th August 1988 earthquake, which was of magnitude 6.6 with epicentre at 25.13°N & 95.15°E(Manipur-Myanmar border), and no destruction was reported within Meghalaya. Although the epicenter was in Manipur and the focus of the earthquake was about 100 km deep, yet the earth shook quite violently in Shillong and the fact that RCC structures withstood the forces of this earthquake admirably, gives confidence in such construction. However, as recommended by the National Disaster Management Authority (NDMA), structural safety audit of all RCC buildings having 5 or more storeys should be conducted and retrofitted if necessary. Structural safety audit has to be carried out also for all schools and colleges, hospitals, the State Secretariat and the Offices of the Deputy Commissioners, power plants & water works, dams and bridges, and other important structures. The task is huge and a lot of trained manpower will be necessary, along with specific testing equipments, for assessing the structural safety of buildings and, thereafter, to carry out strengthening works wherever required. This is a highly technical job and sophisticated tools and machinery, technical know-how, and special materials will be required.

Non-structural Mitigation

There is likely to be considerable damage to furniture in a Class IX MSK Intensity earthquake. Lot of injuries are inflicted, even deaths occur, by falling heavy objects. Therefore, tall, heavy cupboards should be properly fixed to the walls, and heavy objects should be removed from the upper shelves, especially there should be nothing on the shelf over our beds. Large picture frames, mirrors, blackboards, water heaters, bookracks in libraries, etc, should also be fixed securely to the wall. In fact all objects likely to fall, during the vibration of an earthquake, and harm the residents should be fastened properly and restrained from falling.

Other effects of 1897 Earthquake in Shillong

The description of other effects of that great earthquake in and around Shillong, given by Hussain(2005) in the book “From Residency to Raj Bhavan”, besides destruction of the Government House itself, the Government Press, official residences, the jail and the bazaar, are :

(i) The embankment of the Ward’s Lake broke and the water gushed down the ravine to the Wah Umkhrah, destroying the iron bridge to the Polo Grounds. Fortunately, there were no settlements downstream of the dam at that time. Now, if the dam were to break in an earthquake there will be no time to give any advance warning to the residents of the area. The structural safety of the dam has to be checked, if necessary by modeling. The iron bridge has since been replaced by a R.C.C. bridge, but the Wah Umkhrah needs to be cleaned, deepened and widened, with high walls on both banks to increase its water carrying capacity.

(ii) The road to Cherrapunjee beyond Upper Shillong collapsed, and that to Gauhati was blocked by landslides and made impassable by wide fissures. Bull Dozers and other earth moving equipment and some Bailey Bridge units have to be stored at strategic locations, in case of such an eventuality due to an earthquake today, so that communication may be restored at the shortest possible time.

(iii) The water supply broke down and cholera broke out in Mawkhar and adjoining areas. The problem today will be on a much larger scale if history were to repeat itself. Alternate water sources shall have to be identified and pre-disaster contract shall have to be made with private suppliers. Existing springs and streams, which are presently water sources, shall have to be protected.

Response, Rescue and Relief in Shillong

The then Deputy Commissioner, Mr. John Campbell Arbuthnott, and his wife narrowly escaped being buried in there official residence, on the hill above the Ward's Lake. They had just stepped outside on to the lawn, when the building collapsed. Mr. Arbuthnott rushed to the Residency and then to the Secretariat. He was able to save a chaprasi, who was still alive with only his head protruding from the ruins. Thirty persons lost their lives, including Mr. Robert B. McCabe, the Inspector General of Police, who "with characteristic contempt for danger," "refused to run" and was buried in the falling debris of the house. Rescue work was hampered by rain which continued throughout the night until the next afternoon. There was no electric supply then. The streets were then lit with acetylene lamps.

The first couple of nights were horrible, especially for the ladies and children, with the rain adding to the suffering. The survivors spent their nights outdoors. Three small tents, which were originally meant for servants, were somehow retrieved from the debris of the Residency. Some Europeans took shelter in the open grounds, huddling together ten or twelve in each tent. Sir Henry Cotton, the Chief Commissioner, and his family also had to live in tents till temporary accommodation was built. Others took shelter wherever they could find any, in the wooden pavilion of the cricket ground, the sheds of the bazaar, or in the stables and coach houses of the tonga service.

The Chief Commissioner felt that the most urgent works in that moment of crisis were "to house the houseless, feed the people, and restore Communications", and gave orders to the P.W.D. to construct temporary accommodation for the clerks and others. He also authorized construction of huts, free of cost, for private European residents and officers. Regarding food, the Deputy Commissioner could manage to procure only about 2000 quintals of rice, but little else, and he realized that unless the Gauhati- Shillong road was opened there was no hope of getting further supplies. All available officers were entrusted with special jobs. A Forest Officer and one from the Accounts Branch were given the responsibility of getting the road to Gauhati opened. The Assistant Commissioner of Kamrup was placed at Nongpoh to maintain a regular labour service. The Chief Commissioner's Assistant Secretary was assigned conservancy and other municipal duties, while the Chief Secretary, Sir Edward Gait, personally supervised the retrieval of records, files and furniture.

Restoration

The water supply was restored quite quickly while reopening of the Gauhati – Shillong road could be done only by the 8th of July, 1897. Since this road was the only link with the rest of the country, help could not arrive till the reopening of the road and thus the people of Shillong suffered for nearly a month. At present alternate routes are there connecting Shillong to the rest of the country. Safe routes shall have to be identified and maintained for strategic areas.

Reconstruction

The earthquake of 1897 had a decisive influence on the materials of construction and type of structure when rebuilding took place. Stone masonry was clearly unsuitable, which view was corroborated by the Japanese Seismologist, Professor Omori, who had visited Shillong at that time. The design adopted had to be earthquake resistant and thus emerged the Assam –Type houses made of timber. This design has proved successful, over the years, in withstanding earthquakes.

The Government House was rebuilt on the same design and was completed in 1904 at a revised cost of Rs.1,87,713.00.

The owners, of houses which were destroyed in the earthquake, were asked to report the action proposed to be taken by them for rebuilding their homes. The total amount spent in carrying out special repairs to public property and infrastructure in the earthquake affected area was about Rs.37 lakhs, but much more funds were required to restore them to pre-disaster condition.

Funds for Disaster Management

Sir Henry Cotton, the Chief Commissioner, had said that the earthquake had crippled the finances of the Administration for some time and that he did not receive any assistance from the Government of India. He had later written, “The finances of the province during the whole period of my charge were paralysed by the necessity of restoring public works to their former condition and the dial of progress was set back”.

The necessity of having a “Disaster Mitigation Fund” and a “Disaster Response Fund” and the necessity to link the Development Plan with the Disaster Management Plan is amply clear.

The Last Lesson

The Last Lesson is that aftershocks may occur not only for days, but may be for years after the main earthquake. In 1897, the number of shocks and tremors were as frequent as 200 a day for the first couple of days. The earth hardly seemed to be at rest. The aftershocks gradually reduced to around twenty to thirty a day, after a month of the great earthquake of 12th June. Two of the shocks on June the 13th were very strong and were also felt at Kolkata. Till the end of 1898, there was record of 5,523 aftershocks within the region disturbed by the great shock. The decline of the frequency of aftershocks followed a law of seismology and continued for at least 10 years.

Since the aftershocks may be severe, partially collapsed buildings should not be used by the residents, and rescuers or salvagers have to be wary. Temporary shelter have to be provided for the homeless and arrangements for food, water, medicines, sanitation, etc have to be made.

Preparedness and immediate response

The first thing to note is that the earthquake lasted for "about two and a half minutes", which would seem an eternity if we were to experience such an earthquake. The most violent part of the shock was probably a little less than a minute, and even that is a very long time. Usually, earthquakes last a few seconds, giving us no time to react before it is over (for very near epicentral and small earthquakes). But if there is such prolonged shaking of the earth, i.e. if the epicenter is far and the time difference between the arrival of the Primary and the Secondary waves is more, we may have time to find safe places and take protective measures to save ourselves from injury due to falling objects or building collapse. People in the ground floor, at the most those in the first floor, may even rush outdoor to open safe areas but for the residents of upper floors, it would perhaps be futile to try to run down the staircase or use the lift, as both may fail. For such a situation, it is best to take cover wherever we are, along with some drinking water, some dry food, some cash and our essential medicines, etc, and stay calm. A whistle could be vital in attracting attention, if people are trapped inside a collapsed structure. Places in a building where we may take cover are (i) below a sturdy table or bed, (ii) in the doorway, (iii) in the corner of a room or (iv) against an inner wall away from the windows. It is important to drop to the floor, as we may not be able to stand up during the earthquake, and cover our head to protect it from falling objects, and also to hold on to some thing immoveable, if possible.

Preparations for Shillong city

Overview of Shillong city:

Shillong had been the Capital of Assam Since 1874. The City was founded by Col.Henry Hopkinson, Commissioner of Assam in 1864.

Location

Shillong, the Capital City of the State of Meghalaya and also the district headquarter of East Khasi Hills is situated at an altitude of 1496 metres above sea level. It is connected with the rest of the country through Guwahati, the nearest railhead of 103 kilometres.

Area

Shillong, commonly termed as the 'Scotland of the East' has an area of 6436 sq.kms

Wards

27

Population

As per 2001 census, Shillong has a population of 6,01,510.

Important Features of the City

One of the main importance of Shillong City is that, all the State Government Office Secretariat and the important Central Government Offices are located here. The Headquarter of the North Eastern Council is also situated here. The main Schools and College Institutions of Shillong attract the students of the North Eastern Region as well as students from outside the region in institutes like IIM, IIHM, NIFT etc. It is also the Headquarter of the North Eastern Hill University, Eastern Air Command, 101 Communication Zone of the Army and other Para military forces. The Shillong State Library and Museum offer plentiful scopes for study and research of the ethnic cultures in the region.

Transportation

Shillong is well connected by a network of roads within the City and with all important cities in the neighbouring states and other major cities in the country.

Climate and rainfall

The climate of East Khasi Hills District ranges from temperate in the plateau region to the warmer tropical and sub- tropical pockets on the Northern and Southern fringes .The whole district is influenced by the south-west monsoon which begins generally from June and continues till September. The weather is relatively dry between the months of December and March.

Geology and Geomorphology:

East Khasi Hills District is geologically an upland. The straight, steep fault scarp along the southern boundary of the district with the Meghalaya plateau towering over the alluvial plains of Bangladesh is the most characteristic physiographic feature. The plateau top has a hummocky topography, cut through by north- south trending streams along deep gorges. The funnel-shaped gorges along the southern rim are locales for the heaviest rainfall in the world, as at Sohra (Cherrapunjee) and Mawsynram.

The Shillong Group of ancient metamorphic rocks comprising conglomerates, phyllites, schist and quartzites overlying Basement Gneissic Complex, both intruded by granitic plutons and younger basic rocks, constitute the bulk of the exposed rocks in the northern and eastern part of the district. Exposed along the southern rims of the plateau is a near complete sequence of Tertiary sediments overlying the volcanic suite of Sylhet traps, equivalent in age to the Deccan traps of western peninsular India.

Shillong Peak lying 10Kms. from the city, with a height of 1961 Mts. above sea level and being the highest point in the district and the State, offers a panoramic view of the scenic country side.

The southern flank of the plateau is prone to landslides. The district is prone to moderate magnitude earthquakes. The Great Shillong Earthquake of 1897 was the most severe one recorded in India.

Geographically, Shillong lies on the Shillong Plateau which according to the Vulnerability

Atlas of India is seismically vulnerable and lies under Zone-V covering areas liable to seismic intensity of IX and above on the Modified Mercalli (MM) scale.

Socio- Economic Features

The state of Meghalaya attained its full statehood status on the 21st of January, 1972 with Shillong as the State Capital. It was after a period of 21 months when the state of Assam was created on the 2nd of April, 1970. Dr. S.K. Chatterjee, Professor Emeritus, coined the word "Meghalaya" or the "Abode of Clouds".Meghalaya was craved out of the composite State of Assam and it was then that the Khasis, the Jaintias and the Garos realised their cherished dreams for their political aspirations and economic well being. According to the Census report of the Government of India, 2001, East Khasi Hills District, has shown the highest rate of literate persons in the state with 74.74%. When shifting our views to industries, it has been noticed that big industries are scarce, infact absent in East Khasi Hills District which may partially or wholly result in low per capita consumption of electricity annually. Industrial backwardness may also be attributed to various factors, geographical and non- geographical that might have hindered the progress of this sector.

Road transport has become one of the important infrastructural needs of the people in order to help productive activities and mainly for the well being of the society as a whole. Road transport has become the lifeline of the state as far as its economy is concerned. There are also no railway lines in Meghalaya as a whole and East Khasi Hills in particular, the main reason for this is the hilly terrain of the state that renders cheap transportation.

Disaster Management

The main components of the Disaster Management Programme of the United Nations Development Programme (UNDP) and the Government of India including capacity-building to deal with Disasters common to Shillong city, with special emphasis on earthquake resistant features of houses, training in retrofitting, construction of technology demonstration units and development of Disaster Risk Management and Response plans at all levels have been taken into account by the Shillong City Disaster Risk Management Committee .The importance of minimizing the losses to developmental gains and to reducing vulnerability to natural disaster has resulted in the preparation of this plan with a focus of on preparedness and mitigation from reactive to proactive.

Shillong City Earthquake Response Plan

As part of Earthquake preparedness of Shillong City, the District Administration, East Khasi Hills District has been given the responsibility of preparing the Earthquake Response Plan, which is prepared to immediately support and strengthen the efforts of the District Administration, Meghalaya Urban Development Authority and Shillong Municipal Corporation. It is expected that the plan would increase the effectiveness of administrative intervention by describing and performing expected operational activities and by assigning responsibilities for effective co-ordination and implementation of emergency capabilities.

The Shillong City Earthquake Response Plan addresses the city response to an earthquake disaster situation which may affect large areas causing extensive damage to life, property and environment and consequent epidemics which may affect a large population. In any case, the management of this kind of disaster requires extensive resources and manpower for containment by remedial action during and after an earthquake.

Objectives

The plan aims to raise the awareness of decision makers and the general public to the seismic risk of Shillong City.

- It describes an earthquake disaster that may occur in Shillong City.
- It identifies the responsibility which should give an immediate response system in the event of a big earthquake that is to be provided by all levels of Government, by describing and assigning the expected preventive actions to be taken up for additional planning, co-ordination and implementation of emergency capabilities.
- It defines the city specific campaign strategies.
- It is an overview of the basic planning and concept of response for implementation in a variety of situations that may occur.
- It identifies the major concept of administrative management and National support in terms of any kind of resources for fail-proof communication at all levels leaving no gaps and no overlap in times of such emergency in an event of an earthquake disaster.

Strategy

- Formation of Shillong City Earthquake Management Committee and Response Group.
- Preparation of the Earthquake Response Plan by incorporation with other State and Agency plan.
- Sharing of the Response Plan with Stakeholders, response team for awareness generation.
- Sector wise/ Ward wise Earthquke Response Plans and their operation.
- Rehearsal of the Plan / Mock Drill.
- Further recommendations for development.

Coordination

- Co-ordination amongst all Stakeholders who holds the Key to Disaster Management.
- Capacity building of administrative machinery and civil society to cope with disaster more effectively.

Duties of Government and NGOs, before earthquake, during an earthquake and after and earthquake

- Take measures on landslides floods and earthquake.
- Check all buildings and immediately do survey work give warning to the people and evacuated the dilapidated buildings and demolishing them as per rules.
- Emergency services should be taken into proper care.
- Fire and rock falls.
- Falling of building in foothill regions will create a dangerous condition, for such work administration will have to take appropriate action.
- Mobile hospitals, with a team of trained doctors after earthquake action will have to take.
- Recovery vans, cranes, tractors should be ready for the function of earthquake hazard mitigation.
- There should be a training course on earthquake hazard mitigation in all schools and colleges.
- Building cutting, building clearing, building demolishing machine should be available. Properties of buildings and their strength checking instruments should be used.
- Trained dogs body sensitive lights are to be ready for searching survivors trapped inside the ruins.
- Be ready for action by good trained doctors and fire deptt. for rescue and emergency work.
- Keep available oxygen cylinders, other emergency medical equipments so that during such hazard no trouble will be created.
- Emergency portable bridges, big trailer should be ready for clearing goods injured persons, if there are faults, floods and shifting of rivers.

Scientific Observations

What was unusual about the 1897 earthquake was its location. Most earthquakes of this magnitude occur at boundaries of large tectonic plates, some 100 km thick that comprises the Earth's surface.

It was in this earthquake that, for the first time, accelerations exceeding 1g were identified as responsible for propelling objects into the air. From European seismograms Richter calculated a magnitude of Ms=8.7 although retrospective calibration of these same records yields Ms=8.0±0.1. The parameters of the rupture correspond to Mw=8.1. (Bilham et al, 2001)

Further Bilham et al, (2001) interpret the Shillong Plateau as a pop-up structure bounded by (at least) two reverse faults. These faults are referred to as the Olham fault to the north and the Dawki fault to the south. Others have argued that the plateau is bounded by the Brahmaputra fault in the north and the Dapsi thrust in the southwestern part.

The Dauki Fault has a complex evolution in space and time, and is closely associated with the growth and exhumation of the Shillong Plateau. (Biswas et al, 2005).

Our conclusions also raise important issues concerning the seismic hazard potential of the Shillong Plateau. The >300-km length of the Dauki fault has not slipped recently, but were it to slip in a single earthquake its potential maximum magnitude (M 8) (Bilham et al, 2001)

The Kopili fault zone earthquakes in the eastern plateau, Mikir massif region are caused by the long and deep rooted Kopili fault that is transverse to the Himalayan trend. Both the fault zones, the Dapsi/Brahmaputra and the Kopili fault zones, in the Shillong/Mikir plateau are intensely active, but their tectonics are different. The Kopili zone activity is, however, more intensive with higher b-value and higher fractal dimension, and occurrence of an impending large earthquake is speculated in this zone. We surmise precursor study making a multi-parameter observatory on this well-identified active fault is the need of the hour for this seismically most active region of the country. (Kayal et al, 2006)

The occurrence probability of an earthquake M<7 in the region is very high. If a major earthquake expected in the Indo-Burmese Arc (IBA) takes place, the damage in cities like Shillong and Guwahati which are about 300 km away would be disastrous. Strong earthquakes show hypocentres with focal depths around 100 km in the subduction zone and the high amplitude S waves arrive at and additional time around 32 seconds following the arrival of the relatively smaller amplitude P waves. For this reason and taking advantage of the radio wave velocity, a Seismic Alert System (SAS) for Shillong and Guwahati, capable of announcing around 42 seconds before the arrival of earthquakes from the IBA between the window latitudes 24 º N and 27 º N and Longitudes 94 º E and 95 º E, may be planned for installation (Lyngdoh et al, 2009).

A few recent significant moderate earthquakes which shook the region are:

- Bhutan 21st September 2009: Magnitude 6.2, epicentre 27.3°N & 91.5°E
- Myanmar – India(Manipur) border 4th February 2011:Magnitude 6.4, epicentre 24.8°N & 94.5°E

It is interesting to note that the recent 6.4 earthquake which occurred on the 4th February 2011 had its epicentre in the IBA between the window latitudes and longitudes given by Lyngdoh et al (2009).

Figure 2. shows the number of felt earthquakes recorded at the Central Seismological Observatory (CSO), India Meteorological Department, Shillong from 1980 to 2010. In 2011, there are 5 felt earthquakes till this paper was published. There is an increasing trend in the number of felt shocks at Shillong. Interestingly, the Dawki fault has shown very less activity in recent years.

Conclusions

History repeats itself. The old saying goes. One cannot doubt the credibility of this famous saying. As we have seen in the preceding pages about the destruction of the 1897 Great Assam earthquake and also about the preparedness programmes, we have to change the mindset from being reactive to proactive in the sense of underlying the importance of minimizing the losses and focus on the preparedness and mitigation processes. Therefore one must remember that Earthquakes cannot be prevented nor predicted, therefore, we must be prepared at all times.

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Recreating 1950 Earthquake Scenario in 2011

Kishor Jaiswal & David Wald
United States Geological Survey

Based on the request received from Mr. P.G.Dhar Chakrabarti, Executive Director, NIDM New Delhi, and Mr. Saroj Jha and Bernice K. Van Bronkhorst of GFDRR World Bank USA, the United States Geological Survey (USGS) tried to develop an earthquake scenario in the North Eastern India by applying the parameters of 1950 earthquake on the PAGER.

PAGER (Prompt Assessment of Global Earthquakes for Response) is an automated system developed by the USGS that produces content concerning the impact of significant earthquakes around the world, informing emergency responders, government and aid agencies, and the media of the scope of the potential disaster. PAGER rapidly assesses earthquake impacts by comparing the population exposed to each level of shaking intensity with models of economic and fatality losses based on past earthquakes in each country or region of the world.

The USGS's National Earthquake Information Center (NEIC), located in Golden, Colorado, reports over 30,000 earthquakes a year. 25 of these cause significant damage, injuries, or fatalities. To improve the accuracy of assessment of these earthquakes, the USGS has developed PAGER, an automated system for rapidly estimating the shaking distribution, the number of people and settlements exposed to severe shaking, and the range of possible fatalities and economic losses. The estimated losses trigger the appropriate color-coded alert, which determines the suggested levels of response: no response needed (green), local/regional (yellow), national (orange), or international (red).

In addition to direct alert notifications, PAGER provides important supplementary information, including comments describing the dominant types of vulnerable buildings in the region, exposure and any fatality reports from previous nearby earthquakes, and a summary of regionally specific information concerning the potential for secondary hazards, such as earthquake-induced landslides, tsunami, and liquefaction.

PAGER results are generally available within 30 minutes of a significant earthquake, shortly after the determination of its location and magnitude. However, information on the extent of shaking will be uncertain in the minutes and hours following an earthquake and typically improves as additional sensor data and reported intensities are acquired and incorporated into models of the earthquake's source. Fundamental to such a system, the USGS operates a robust computational and communication infrastructure necessary for earthquake response.

Earthquake Scenario Parameters:

For creating an earthquake scenario for North Eastern India USGS applied the following well observed and documented parameters of the earthquake of 15 August 1947.

Source Parameter	Values Used	Reference
Magnitude	8.6	Kanamori (1977)
Epicenter Location	$28^0$23'N, $96^0$41'E	Ben-Menahem et al. (1974)
Hypocenter Depth	35 km	Vary from 22 km to 35 km
Fault Length	250 km	Ben-Menahem et al. (1974)
Fault Width	80 km	Ben-Menahem et al. (1974)
Fault Depth Range	3 to 68 km	Computed from geometry
Azimuth of Strike	330^0	Ben-Menahem et al. (1974)
Dip of Fault	55^0	Ben-Menahem et al. (1974)
Fault Mechanism	Strike-Slip (SS)	Ben-Menahem et al. (1974) Kayal (2010)
Macro-seismic Intensity Observations	49 observations (IV to IX) for 1950 Assam earthquake	Martin and Szeliga (2010)

Shaking Hazard Estimates

Shaking hazard was estimated applying the USGS ShakeMap Methodology, Wald et al. 2005:

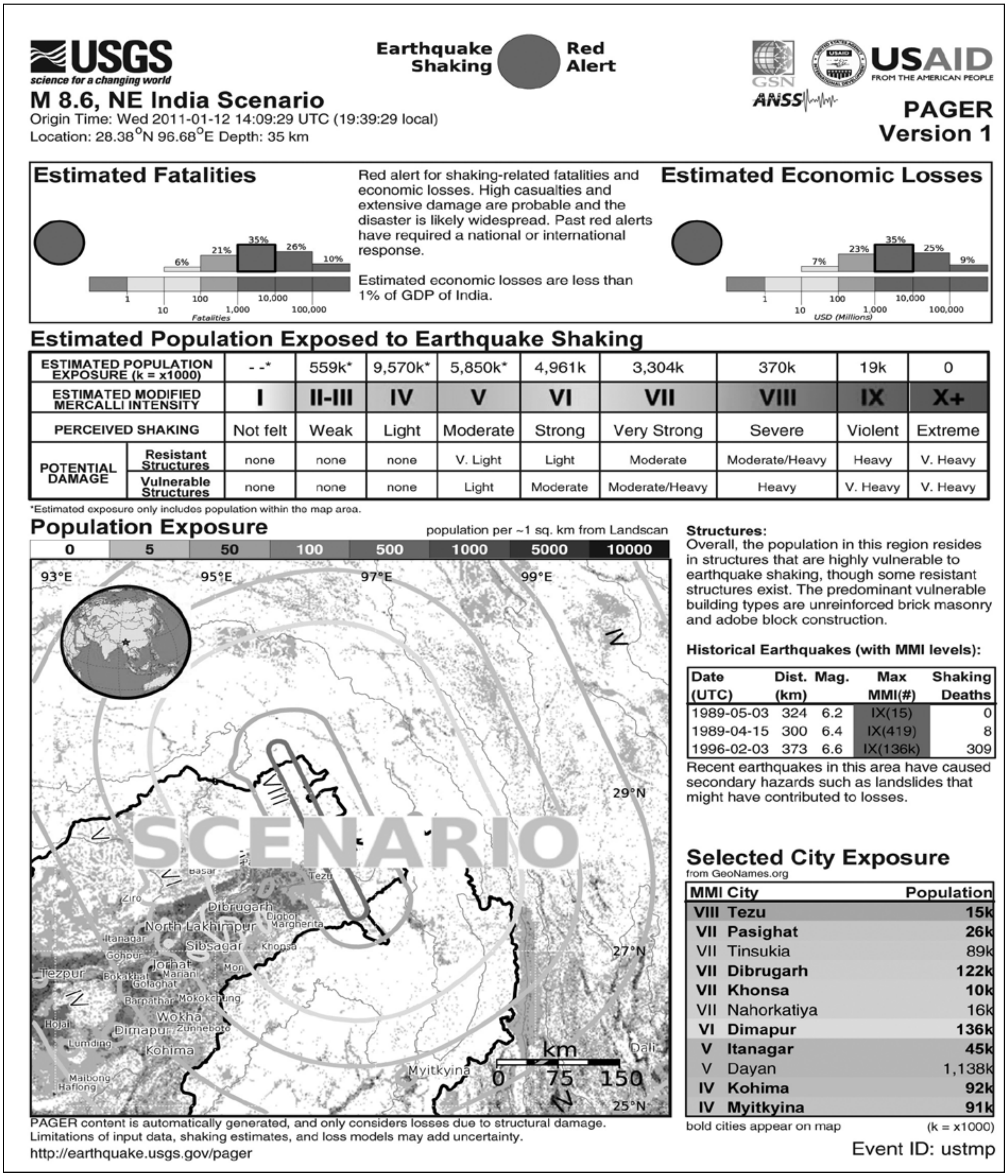
Parameter	Model
Map Boundary	"92.683333E/100.683333E /24.863333N/31.903333N"
Ground Motion Prediction Equation	Chiu and Young (2008)
Site Correction	Slope vs. Vs30 model
Max. PGA estimated	0.72 g
Max. PGV estimated	83 cm/sec
Max. Intensity (MMI scale)	IX

Earthquake Loss Estimates

The earthquake loss estimates were made on the basis of USGS PAGER Methodology:

Screenshot from PAGER's Earthquake Scenario in North Eastern India based on the parameters of 1950 earthquake

Parameter	Model
Earthquake Exposure	Approx. 19,000 people may experience violent shaking and 370,000 people may experience severe shaking which generally contribute to heavy damage. Approx. 14 million people may experience moderate to very strong shaking during such earthquake.
List of Cities that may be affected	Tezu city in Arunachal Pradesh (15,000 population), Pasighat in Arunachal Pradesh (26,000 population). See the list on PAGER summary page.
Earthquake Fatality Estimates	Estimate fatalities from PAGER model indicate a “red alert” for fatality losses in this scenario. High casualties are probable in such scenario.
Total Direct Economic Loss (in US dollars for 2009 value)	PAGER estimate “red alert” for economic losses. The damage and economic impact will be widespread and may require national or international response.
Impact	Refer to Figure 1. Economic: Red Alert Fatality Losses: Red Alert



USGS
science for a changing world

Earthquake Shaking Red Alert

GSN ANSS USAID FROM THE AMERICAN PEOPLE

M 8.6, NE India Scenario
Origin Time: Wed 2011-01-12 14:09:29 UTC (19:39:29 local)
Location: 28.38°N 96.68°E Depth: 35 km

PAGER Version 1

Estimated Fatalities

6% 21% 35% 26% 10%
1 10 100 1,000 10,000 100,000
Fatalities

Red alert for shaking-related fatalities and economic losses. High casualties and extensive damage are probable and the disaster is likely widespread. Past red alerts have required a national or international response.

Estimated economic losses are less than 1% of GDP of India.

Estimated Economic Losses

7% 23% 35% 25% 9%
1 10 100 1,000 10,000 100,000
USD (Millions)

Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	559k*	9,570k*	5,850k*	4,961k	3,304k	370k	19k	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan

0 5 50 100 500 1000 5000 10000

Structures:
Overall, the population in this region resides in structures that are highly vulnerable to earthquake shaking, though some resistant structures exist. The predominant vulnerable building types are unreinforced brick masonry and adobe block construction.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1989-05-03	324	6.2	IX(15)	0
1989-04-15	300	6.4	IX(419)	8
1996-02-03	373	6.6	IX(136k)	309

Recent earthquakes in this area have caused secondary hazards such as landslides that might have contributed to losses.

Selected City Exposure
from GeoNames.org

MMI	City	Population
VIII	**Tezu**	**15k**
VII	**Pasighat**	**26k**
VII	Tinsukia	89k
VII	**Dibrugarh**	**122k**
VII	**Khonsa**	**10k**
VII	Nahorkatiya	16k
VI	**Dimapur**	**136k**
V	**Itanagar**	**45k**
V	Dayan	1,138k
IV	**Kohima**	**92k**
IV	**Myitkyina**	**91k**

bold cities appear on map (k = x1000)

PAGER content is automatically generated, and only considers losses due to structural damage.
Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Event ID: ustmp

Figure 1: PAGER's shaking, exposure and earthquake loss estimates for a hypothetical scenario earthquake in Northeast India

Clarifications

The following issues need to be clarified for drawing conclusions from this study:

- This is a hypothetical scenario earthquake chosen based on discussion with Indian counterparts. The location, depth, magnitude and other parameters etc. are inferred based 1950 earthquake in this region.
- This is neither a 'worst-case' scenario nor a 'most-likely' scenario for this region. In fact, we did not study the relative frequency of such earthquake in this region to infer anything on future occurrence rate of such earthquake.
- Earthquake losses are cumulative of entire affected region, which includes countries primarily India, China, Myanmar and Tibetan region.
- Most affected region for this scenario is estimated to be Assam state of India.
- Earthquake fatality and direct economic losses are estimated using 2009 population and economic indicator data.
- Earthquake loss estimates have large uncertainty as depicted in PAGER's loss estimate. This is not uncommon due to number of factors/parameters that are either poorly constrained or simply not known.
- Detailed investigations are necessary in order to reduce some uncertainty associated with different model parameters.

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Earthquake Prediction in Northeast India - A Review

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Abstract : *A multidimensional geophysical approach is made to study earthquake precursors in northeast India. Resistivity, gravity and seismological precursor anomalies for the two recent damaging earthquakes, one on December 30, 1984, magnitude 5.8, and the other on August 6, 1988, magnitude 7.5, are very encouraging to intensify these studies in the region. Improved methods of magnetic and geohydrological precursor studies are suggested. Key words: Precursor, resistivity, magnetic, gravity, earthquake swarm, microseismicity-rate, velocityratio, radon gas.*

Introduction

Seismically, northeast India is one of the most active regions of the world. Two great earthquakes, one in the Shillong Plateau (1897) and the other on the Assam-Tibet border (1950), both of magnitude 8.7, occurred in this region (RICHTER, 1958). There were as many as 17 large earthquakes of magnitude > 7.0 in the past century within the latitude 22-30~ and longitude 90-97~ of the region (Figure 1). The seismotectonics of northeast India has been summarised as the south directed overthrusting from the north due to collision tectonics at the Himalayan arc, and northwest directed overthrusting from the southeast due to subduction tectonics at the Burmese arc (e.g., TAPPONNIER and MOLNAR, 1976; VERMA et al., 1976, 1977; KAYAL, 1989). Recently a few microearthquake surveys in the Shillong Plateau and adjoining areas have revealed a high level of seismicity, and the source mechanisms of the microearthquakes indicate that the Plateau is under compressional stress (KAYAL, 1987; KAYAL and DE, 1991).

Many authors have suggested that northeast India is now due for a large earthquake. KHATTRI and WYss (1978) have demarcated a zone, which they have defined as the Assam Gap for an impending large earthquake (Figure 1). GunA and BHATTACHARYA (1984) have reported a significant precursory decrease in b-value in this region, and indicated the probability of occurrence of a great earthquake (Mag. >8) in the near future. GUPTA and SINGH (1982), on the basis of P-wave travel-time residual, have reported that the Shillong Plateau is undergoing a dilatancy stage, precursory to a large earthquake. Further, GUPTA (1985) has emphasised that the Cachar earthquake of December 30, 1984 might be the

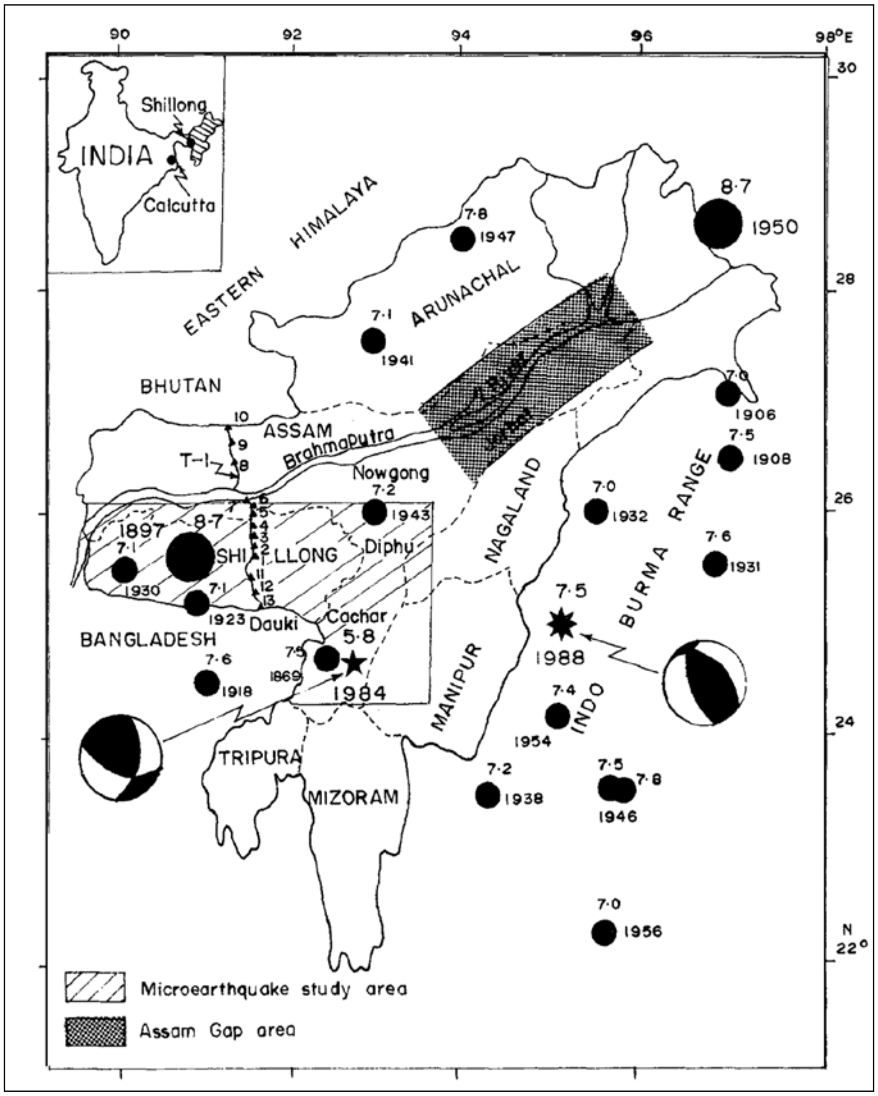

Figure 1: Epicenters of the large earthquakes (magnitude >- 7.0) including the two great earthquakes (magnitude > 8.0) in northeast India. The great earthquake of 1897 is the first instrumentally recorded earthquake in the region. The epicentre of the 1869 earthquake is reported to be in the Cachar area; its location in the map may not be correct. The two recent damaging earthquakes are shown by solid stars. Focal mechanisms of these earthquakes are also shown (see text); shaded areas indicate the zone of compression and the open areas indicate the zone of dilatation. Microgravity traverse (T-1) from Dauki to the Assam-Bhutan border is shown; the solid triangles indicate the fixed gravity stations. Station 1 is in the Shillong town area where resistivity, magnetic and geohydrological measurements were made. (Inset: key map; hatched area is shown in the map.)

beginning of a seismically active period like that of one from 1869-1943 in the Shillong region where six large earthquakes, including the great earthquake of 1897, occurred during the period (Figure 1).

In recent years, various geophysical surveys have been carried out to monitor precursor anomalies before the felt or moderate earthquakes in this region. The available data of geoelectrical, geomagnetic, microgravity, geohydrological and seismological precursors as well as post-earthquake information for the two recent damaging earthquakes in this region, one on December 30, 1984 and the other on August 6, 1988, are studied here.

Cachar Earthquake of December 30, 1984

The Cachar earthquake of December 30, 1984, magnitude: 5.8, origin time: 23 h 33 m 39.1 s, latitude: 24.598° N longitude: 92.939° N restricted depth: 33 km (USGS report), rocked the entire area during the early hours of December 31, and was responsible for the loss of 20 human lives and considerable damage to buildings, bridges, roads, huts etc. (Figure 2a). Fissures, ground cracks and subsidence were prominent in the area; sand and water were discharged from the fissures and vents. The maximum intensity of the earthquake reached VIII on the Modified Mercalli Scale (unpub. data, Geol. Surv. India). DUBE et al. (1986) studied the focal mechanism of the earthquake, and inferred a thrust-fault solution with a strike-slip component and a dominant compressional stress in the NE-SW direction (Figure 1).

Figure 2 : (a) Damage of a mud hut in the Cachar area caused by the earthquake of December 30, 1984.

Manipur-Burma Border Earthquake of August 6, 1988

The Manipur-Burma border earthquake of August 6, 1988, magnitude: 7.5, origin time: 00h 36m 26.9 s; latitude: 25.116~ and longitude: 95.171~ depth: 115 km (USGS report), rocked the entire northeastern region of the country early in the morning of August 6, 1988 at 6.10 a.m. (local time). The tremor was felt throughout northeast India, Bangladesh and parts of Burma. It lasted approximately two minutes, and caused a loss of four human lives, considerable damage to buildings,

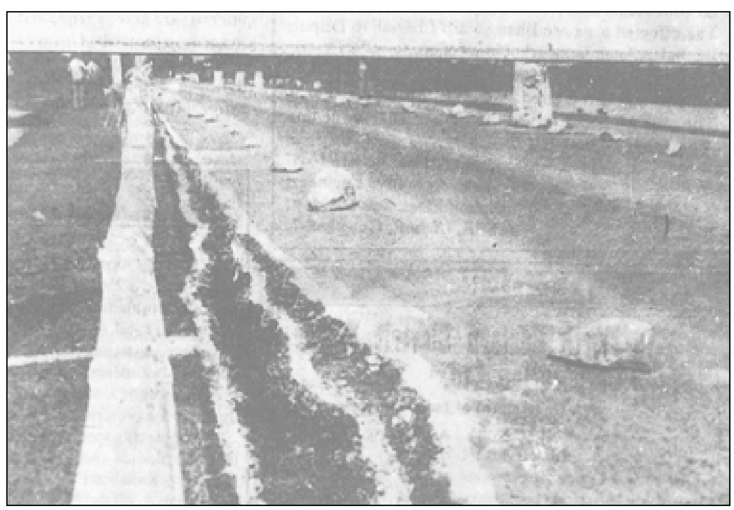

Figure 2 : (b) Damage of the National Highway in the Nowgong area caused by the Manipur-Burma border earthquake of August 6, 1988.

railway tracks, roads etc. (Figure 2b). Field surveys showed that the maximum intensity reached VIII on the Modified Mercalli Scale (unpub. data, Geol. Surv. India). The survey revealed three areas (viz, Jorhat, Silchar and Diphu) where maximum damage was recorded. Landslides, formation of fissures through which sand, mud and water were ejected in these areas, were observed. The focal mechanism study showed a thrust-fault solution (Figure l), and it inferred a compressional stress parallel to the trend of the tectonic feature of the Indo-Burma range (BANGHAR, 1990).

Observed Precursor

Resistivity

An innovative dipole-bipote field set-up was made to carry out the precursor resistivity measurement at two fixed stations in the Shillong area during 1984-1987 (KAYAL and BANERJEE, 1988). At each station measurements were made along four directions which were azimuthally separated by 45 ~ (Figure 3a). The two receiving stations, S-1 and S 2, were selected on two different geologic formations; S-1 on quartzite and S 2 on Phylite formations. Twelve to 14 days before the Cachar earthquake the resistivity values decreased by about 40-50% in all four measured directions at S-2, but a 40% decrease was observed in only one measured direction at S-1 (Figure 3b). Immediately after the Cachar earthquake there was a sequence of earthquakes, magnitude 3.6-4.7, to the northeast of Shillong, and the resistivity anomaly continued until the energy release was complete. It should be mentioned that before the Cachar earthquake two earthquakes of magnitude 4.6 and 4.2

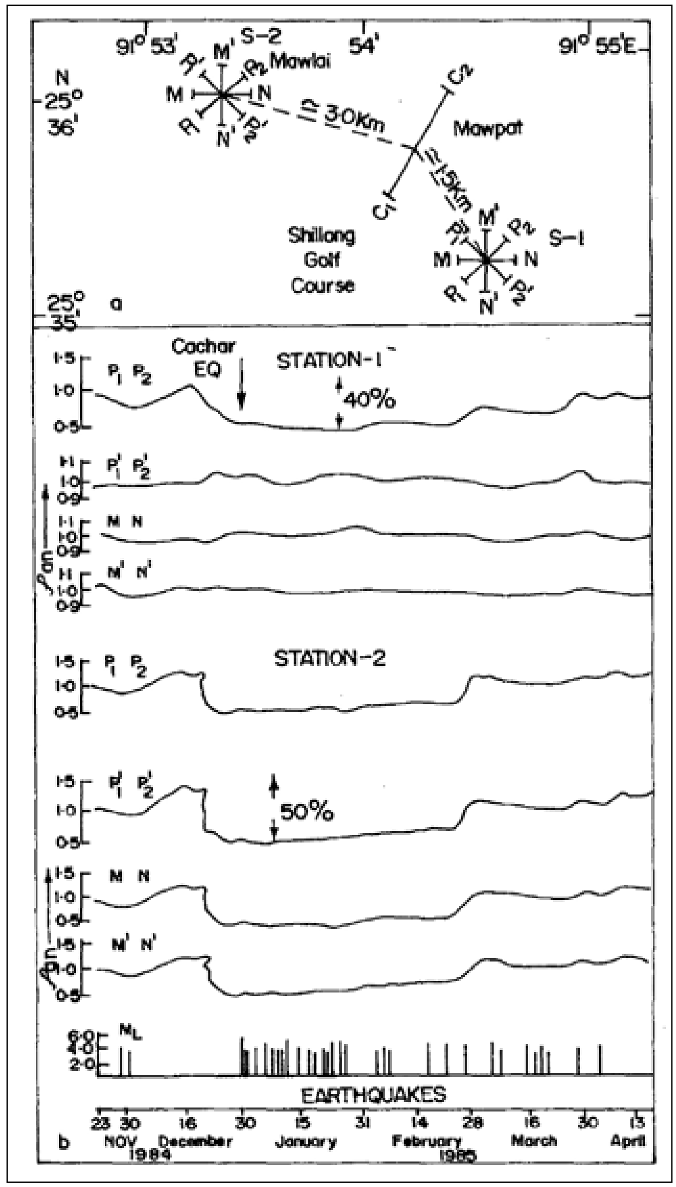

Figure 3 : (a) Location map of resistivity survey and the electrode arrangements used in this study. (b) Temporal change of earth resistivity and occurrence of felt earthquakes in the Shillong area. P,n is the normalised apparent resistivity. The solid arrow indicates the occurrence of the Cachar earthquake (after KAYAL and BAr~ZRJEE, 1988).

occurred in the area on November 28 and December 2, 1984 respectively, and a 12-20% decrease in resistivity value was also observed as above (Figure 3b).

Magnetic

Magnetic measurements were made employing a Scintrex digital Fluxgate magnetometer MED 4 at the base camp of the above resistivity survey in the Shillong area. Two readings were taken daily. Total vertical component of geomagnetic field was observed. Temporal variation of geomagnetic field is shown in Figure 4. Two daily observations showed only fluctuations in the magnetic value rather than any precursory anomaly (Figure 4a). The mean of the two daily observations was also plotted (Figure 4b), but no anomalous change in magnetic value was observed before the Cachar earthquake.

Gravity

No precursor gravity measurement was made before the Cachar earthquake. Post-earthquake gravity variations were studied by ARUR et al. (1986). They carried out two microgravity surveys, one in May 1985 and the second in November 1985, reoccupying their (Survey of India) gravity stations of February, 1976. Post-gravity changes from +65#gal to -105#gal were reported, indicating subsidence and elevation in different parts of the area, and the epicentre of the earthquake was located in the zone of transition from subsidence to elevation.

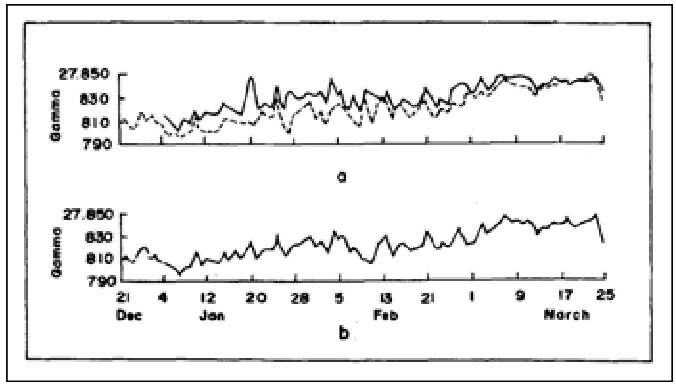

Figure 4 : Variation of total magnetic field with time in the Shillong area. (a) Plot of two observations in a day and (b) plot of the average of the above two observations (after KAYAL et al., 1989, unpub, report, Geol. Surv. India).

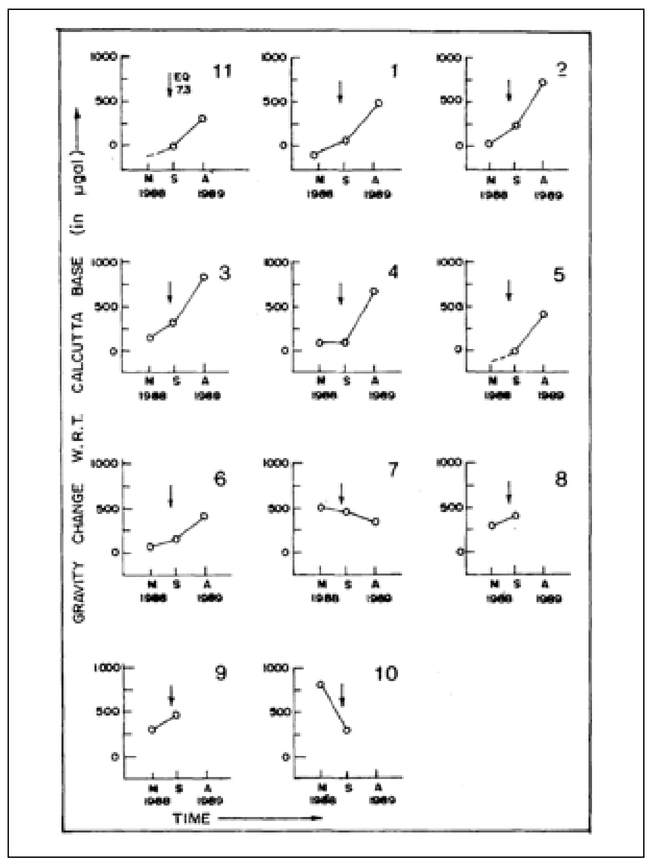

Figure 5 : Change in microgravity values at fixed stations along the traverse T-I (Figure 1) with respect to the Calcutta base. The stations in the Shillong Plateau show an increasing trend and the stations in Brahrnaputra valley show a decreasing trend except the stations at 8 and 9
(after KAYAL et al., 1989, unpub, report, Geol. Surv. India).

We carried out three repeat microgravity measurements along a fixed traverse (T-l) across the Shillong Plateau and Brahmaputra valley, from Dauki to the Assam-Bhutan border, during 1988-89 (Figure 1). The observed changes at each fixed station, with respect to the Calcutta base were plotted (Figure 5); it showed an increasing trend of microgravity values in the Shillong Plateau and a decreasing trend in the Brahmaputra valley after the large earthquake of August 6, 1988.

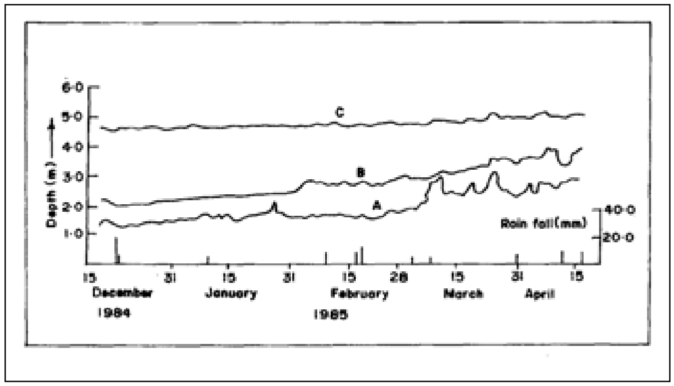

Figure 6 : Daity variation of welt water-level in the Shillong area recorded at three shallow dug-wells A, B and C (after KAYAL et al., 1989, unpub, report, Geol. Surv. India).

Well Water-level

Well water-level measurements were also carried out in three shallow dug-wells (depth < 5 m) in the resistivity study area, Shillong Golf Club. Daily fluctuations of the well water-levels along with the rain-fall data are shown in Figure 6. No significant change in well water-level and/or correlation with the earthquakes were observed. Precursor changes, if any, might be masked by the human use of the well water as these wells were situated in populated areas of the Shillong town, or, these wells were just too shallow to produce any precursory change in water-level.

Radon Content

DEu et al. (1990) reported a diagnostic precursor anomaly of the radon content in formation water before the Cachar earthquake. A 30-40% increase in radon-gas was reported by them (pers. comm., 1990) for the samples of a deep hole in the Dauki area which was nearer to the epicentre (Figure 1). A similar significant variation in radon content of well water in the Shillong town was also observed for the August 6, 1988 Indo-Burma border earthquake (KHARSHIING, A. D., North Eastern Council, Shillong, pers. comm., 1988).

Earthquake Swarm

GUPTA and SINaR (1989) studied the earthquake sequences which occurred before the December 30, 1984 and August 6, 1988 earthquakes. They studied the seismicity pattern in different time-intervals within a 5-6 ~ window, and suggested that the precursory swarm hypothesis of EvISON (1977) could be made predictive in this region. Figure 7 demonstrates the observation of background/normal seismicity, swarms and quiescence preceded by the two damaging earthquakes in this region.

Microseismicity

Four microearthquake surveys were carried out during 1983-86 by a temporary five-stations network in different parts of the Shillong Plateau and adjoining areas (KAYAL, 1987; KAYAL and DE, 1991). Based on the above microearthquake data, temporal change in microseismicity-rate was studied. The microearthquakes, duration magnitude 1.0-3.5, which were recorded within 30 km radius of the network, were considered. A change in microseismicity-rate before the Cachar earthquake was observed (Figure 8). A high level of microseismicity, on average 40 events per month, was observed in early 1984, and the seismicity level decreased to the normal/ background rate, on average 16 events per month, following the Cachar earthquake. It should be noted that no aftershock sequence was observed after the Cachar earthquake (DuBE et al., 1986).

The crustal velocity-ratio (Vp/Vs) of the Shillong Plateau was also studied by the Wadati-plot method, using the above microearthquake data (DE and KAYAL, 1990). There was a data gap in the temporary microearthquake networks, but a decreasing trend in the Vp/Vs value before the Cachar earthquake might be speculated (Figure 9).

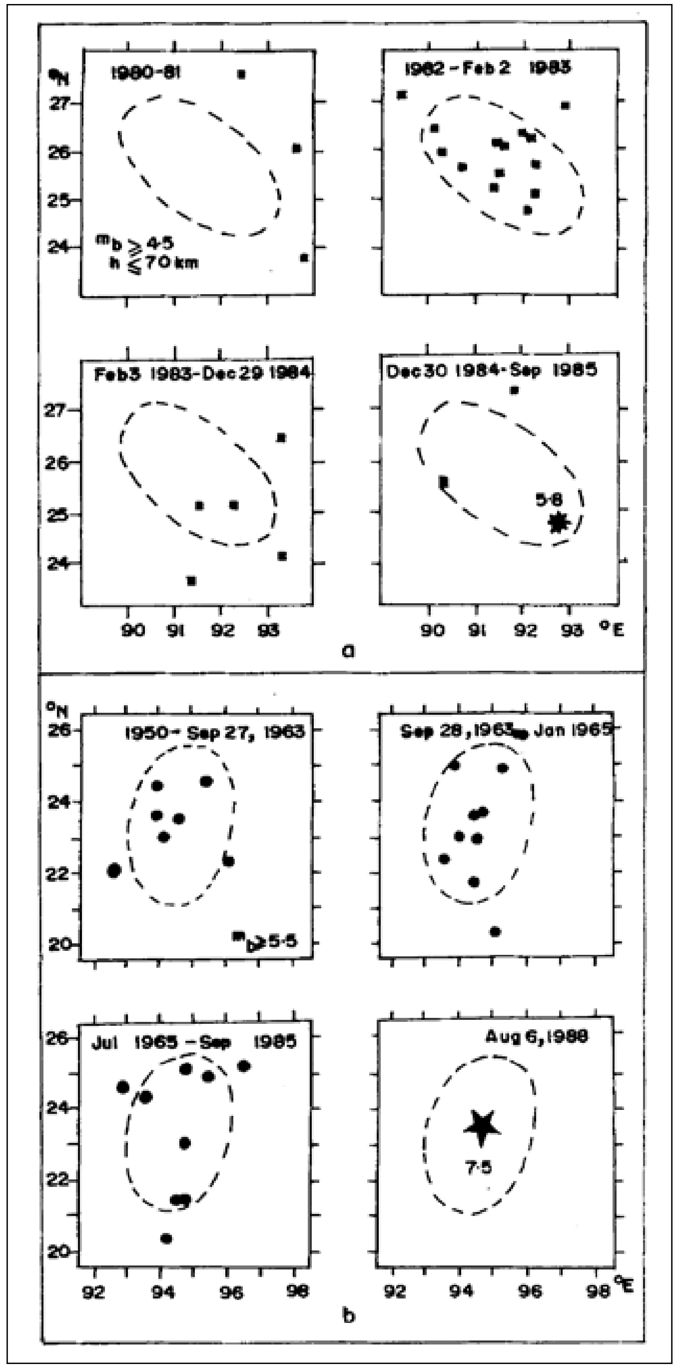

Figure 7 : Precursory swarm of earthquakes before the two damaging earthquakes. (a) Normal seismicity, swarm, quiescence and the main shock of December 30, 1984. (b) Normal seismicity, swarm, quiescence and the main shock of August 6, 1988 (after GUPTA and SINGH, 1989).

Discussion

Resistivity

There is a valid correlation between the resistivity anomaly and the occurrence of earthquakes in the Shillong area (Figure 3). The decrease in apparent resistivity may be explained

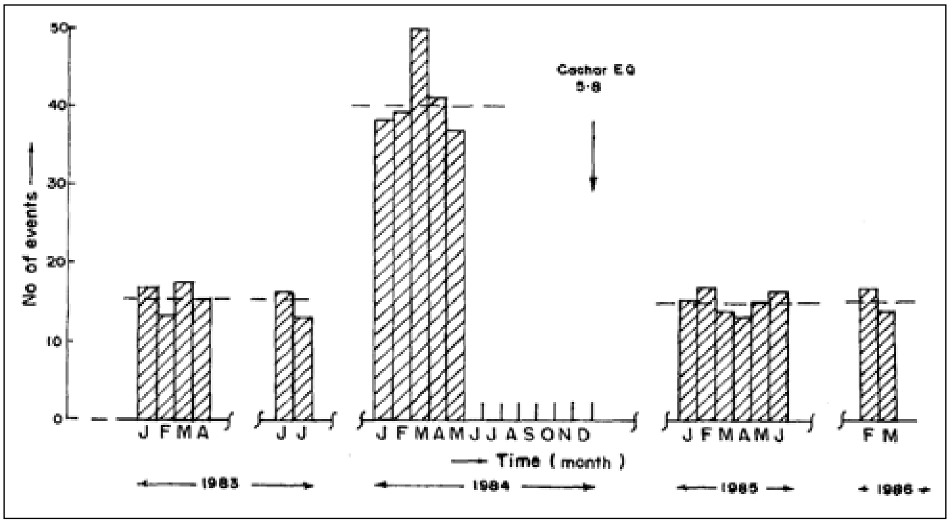

Figure 8 : Change in microseismicity rate befoe and afterthe Cachar earthquake. The microearthquakes, duration magnitude 1.0-3.5 recorded within 30km radius of the networks in the study area are used

by the dilatancy model of SCHOLZ et al. (1973); formation of new cracks and/or extension of existing cracks or reopening of old cracks, subsequent filling of water prior to energy release by earthquakes is responsible for lowering the resistivity values (e.g., BARSUKOV, 1972; MAZELLA and MORRISON, 1974; YAMAZAKI, 1975; QIAN, 1984; QIAN et al., 1984; SIDORENKO et al., 1984). However, MORRISON et al. (1979) reported a negative result in precursor resistivity for an earthquake of magnitude 4.0 in California. KAYAL and BANERJEE (1988) have suggested that such negative results or insignificant resistivity changes are possible; prior to earthquakes resistivity may increase or decrease or may indicate no change at all, depending on the orientation of the measuring electrodes, rock type and direction of stress/fracture orientation. For the Cachar earthquake we have also observed here insignificant resistivity changes in the three measured directions at station 1 (Figure 3b), which is similar to that observed by MORRISON et aL (1979). Vol. 136, 1991 Earthquake Prediction in Northeast India 309 Thus, for earthquake prediction it is imperative that resistivity measurements are made, using at least two sets of orthogonal directions at the receiving station.

Magnetic

Whether a geomagnetic field changes before an earthquake, has been argued by many authors (e.g., STACEY, 1963; RIKITAKE, 1968; SMITH et al., 1976; JOHNSTON, 1978). In his review work, RIKITAKE (1976) has reported that a 5-15 gamma change in a geomagnetic field may be expected to accompany an earthquake of moderate magnitude. Guo-HuA et al. (1984) made an extensive study of geomagnetic total-field employing a proton precision magnetometer at 108 pairs of stations before the Tangshan earthquake of 1976, and reported a seismomagnetic effect

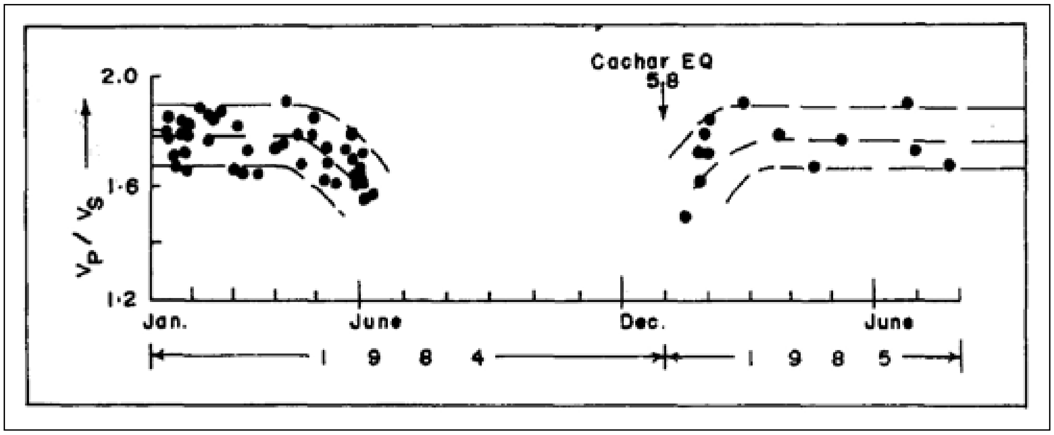

Figure 9 : Temporal variation of velocity-ratio (Vp/V~) before the Cachar earthquake (after DE and KAYAL, 1990).

both in time and space. Although the geomagnetic measurement has not shown any diagnostic anomaly in this study, this does not preclude the possibility of detecting geomagnetic changes before a major earthquake in this region. It is desirable to make use of a large array of more precise magnetometers, intensive study with large sets of data and techniques for eliminating various sources of noise like magnetic storm, diurnal and seasonal variations, etc.

Gravity

In a tectonically active region gravity changes are observed due to variations in elevation and redistribution of mass. Many authors have reported such gravity changes: e.g., BARNES (1966) in U.S.A., KISSLINGER (1975) in Japan, HAGIWARA (1978) and CHEN et al. (1979) in China. Gravity changes from -325#gal to + 165 #gal were reported before the 1975 Haichang earthquake, magnitude 7.3, and the 1976 Tangshan earthquake, magnitude 7.8, respectively (CHEN et al., 1979). The 1964 Alaskan earthquake, magnitude 8.6, indicated a gravity change of over 200 pgal at Valdez (BARNES, 1966). In India ARUR et al. (1986) reported postearthquake gravity changes of -65 #gal to + 105 #gal following the 1984 Cachar earthquake, magnitude 5.8. The repeat microgravity measurements in this study, though limited with data, also indicate that a large earthquake is associated with precursor gravity changes in the area. Repeat microgravity and also geodetic surveys would be useful for precursor as well as for pre-earthquake/post-earthquake crustal deformation studies in this region.

Geohydrology

LIu-CHA and SHAN-YIN (1984) have reported spouting and pressure increase in oil wells and rise of well water-level in the epicentral areas before 14 large-tomedium earthquakes in China. A number of cases are known in which geohydrological precursors like changes in the level or pressure of ground water take place several days or hours before an earthquake (e.g., MAVASHEV, 1974; SADOVSKY et 310 J.R. Kayal PAGEOPH, al., 1977, 1984). In all cases, measurements were taken in deep boreholes. QIAN (1984) suggested that squeezing and/or infusion of water in interconnected fractures located at depth may cause a change in the water table due to an earthquake.

Well water-level measurements for precursor study in this region need to be improved. Deep boreholes should specially be made in isolated areas away from towns or villages, and regular monitoring of the water-level should be made by a responsible person in the area.

Variation of radon gas in well water and/or in mud samples in an epicentral area of medium-to-large earthquakes was reported by HAUKSSON (1981) and ROBINSON and WHITEHEAD (1986). A wealth of data regarding geochemical measurements are presented in a review work by KING (1980, 1981). In India, GHOSH et al. (1987) reported that 65.5% of earthquakes recorded by the seismograph station at the Shillong Observatory were correlatable with a variation of radon gas in the well water in the area. The variations of radon gas in well water before the two damaging earthquakes reported here are also encouraging. The development of advanced technology and systematic measurements of radon gas in specially made deep boreholes is suggested for precursor study in this region.

Seismology

Seismological observations in this study such as earthquake swarm (Figure 7), microseismicity rate (Figure 8) and crustal velocity-ratio (Figure 9) further support the predictive hypothesis of seismological precursors before large earthquakes as have been reported in other parts of the world (e.g., EvIsoN, 1977, 1982; HABERMANN and WYSS, 1984; AGGARWAL et aL, 1973; FENG et aL, 1974). GUPTA and SINGH (1986), based on the observations of earthquake swarms for the 1950 earthquake, magnitude 8.7 and for the 1984 Cachar earthquake, magnitude 5.8, predicted the Manipur-Burma border earthquake of August 6, 1988, magnitude 7.5, and claimed that their forecast was accurate (GUPTA and SINGH, 1989). Although the microseismicity and velocity-ratio data are meagre in this study, the inferences drawn by these studies suggest that continuous monitoring of microseismicity in this region by permanent networks would be useful for prediction research.

Conclusion

Summarising what has been stated in the preceding sections, it may be concluded that the precursor studies in northeast India have given us some understanding of a general philosophy of earthquake prediction in this region. The prediction of the Manipur-Burma border earthquake of August 6, 1988 by GUPTA and SINGH (1986, 1989) though it sounds promising, it should be borne in mind Vol. 136, 1991 Earthquake Prediction in Northeast India 311 that precursory signals are likely to differ from earthquake to earthquake. Precursors of the multidimensional geophysical approach, as exemplified in this study, should be performed throughout the supposed earthquake-threatened areas of the region for any practicable and successful earthquake prediction with space and time.

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Landslides: A Major Geohazard in North Eastern India

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Abstract: *North Eastern Region of India is poised for active development in the field of infrastructural facilities. But the high incidence of the landslides are detrimental for this process. The immature topography, deep and widely extended weathering profile, young mountains with soft rock mass coupled with higher order of precipitation and intense demographic pressure are responsible for the geodynamics of the landslides. The high seismic status of North Eastern Region requires an integrated analysis for identifying the different types of the landslides with their geological relevance and causative factors. These are worked out during this study. The paper also highlights the working strategy of landslide Disaster Management by preparing a land slide hazard zonation map wherein an input of landslide incidences has been highlighted to identify the broad but specific targeted areas for implementing the mitigation action plan effectively and economically.*

Introduction

The Northeastern India with vast natural resources is poised for all round development. The main activities being expanding urban agglomeration and exploitation of hydel power potentials of its mighty rivers, the expansion of existing communication network, both road and rail is essential not only for facilitating the construction work but also to link far flung small settlements with rest of the country through trunk routes. Landslides, the outward and downward movements of material detached from the main mass along a plane of separation in this region occur in such frequency and abundance that they are major hindrance in these activities. The high incidences of mass movements in young, hilly topography is due to weathered and weakened nature of rock mass resulting from greatly variable temperature and triggered by heavy rains and frequently recurring seismic shocks. The water flowing in innumerable streams and channels of Lohit and Barak systems weakens, erodes and toe cut the valley slopes generating series of landslides that contribute largely to general topographic degradation. Though not on this scale, human interference also contributes consistently in slope instability.

Thus, the hazardousness of landslides being of very high magnitude their mitigation (since prevention is not possible) and as a prerequisite demarcation in terms of incidences and potentiality, both, are high priority objectives. The study of landslides on both macro and micro levels has been highlighted. The macro level investigations by way of preparing landslide (hazard) zonation maps which classify slopes in terms of incidences and potentiality to sliding are essential ingredient of mitigation strategy. The study of all individual landslides is impossible, thus it is imperative to survey and selectively studied them in details. The knowledge gathered from these investigations has greatly helped in identifying the failures inherent in the slopes and also those contributing to sliding, its application in other areas to demarcate the susceptible zones with potentiality of sliding has practical utility.

Some Important Landslides

The incidence of the landslides are distributed in the seven states of the North Eastern Region But several important landslides are described in the following text.

Arunachal Pradesh

The high incidence of landslides along Moying-Migging- Tutting road and Bhalukpong- Tenga -Bomdila road has been studied. The high altitude road section of Bomdila- Tawang and Zemithan ¬Nelya roads are also badly affected by rockmass movements. In most of the cases the deep weathering profile, partially translated into thick overburden supported by weak slope forming rock mass under heavy saturation and due to constant removal of the toe support by the perennial Nala/river are the major causes of landslides. Also the loss in frictional resistance due to presence of thick clayey overburden under heavy saturation leads to failure of weak rock mass as well as clayey loose material. In addition, in several sections steep slopes to hill spurs are characterised by seepage in over burden and piping action under heavy saturation, generating conditions conducive to slope failures.

Assam

Landslides are mainly concentrated in softer rocks and seismically active area aided by heavy rainfall. The problem gets accentuated by extensive deforestation and unorganised growth of town on hill slopes. Oldham (1899) while describe co-seismic landslides in 1897 Great Assam Earthquake observed that high hill slopes in Assam and Meghalaya were much more affected by landslides in comparison to the low lying hill slopes. The record of landslides incidence clearly show that the thickness of weathered zone/soil zone is fairly high and many of the landslide incidents are due to anthropogenic activities. Most of them are slump type followed by debris slide, rock slide and rock fall.

A prominent landslide located at the foothills of Navagraha temple in Guwahati caused slipping down of wall boundary of a house along the slope in the year 2002. There were four casualties in July 1999 at north Kalapahar, where in the vicinity more people had already died in August 1987 due to another slide. In both the cases causative factors were heavy rains. In 1982 at Birubari the death toll of 4 people was also on account of heavy rainfall followed by a landslide.

Manipur

The 50 TPD Capacity Hundung cement plant, Ukhrul District, Manipur, located on landslide debris subjected to bull dozing for making a platform. During this process oflevelling the overburden generated was dumped on the slopes and in the depression without achieving optimum level of compaction (Gupta, Avasthy & Bhatia, 1992).

The charging of the foundation grade and slope forming material through surface and subsurface flow and shaking of the ground through the vibrations generated by the Operations of different machineries appear as the major causative factors leading to differential settlement and slope instability.

Meghalaya

The slide located at 141.65 km from Shillong on Shilong-Silchar highway is of great significance as the highway is the life line which can be gauged from the fact that 600-800 vehicle pass through the affected area to reach Silchar daily. The slide first occurred on 7th July, 1988 following heavy rainfall in the area and is reported to have pushed a truck passing through the failing slope into the river. Investigations revealed that it was essentially a debris slide in which the debris lying above a sequence of alternate bands of sandstone and siltstone got mobilised due to erosion at the river bed level abetted by the development of pore-pressure (Eckel, 1958) in the overlying debris. The failed mass damaged the road and moved down into the river causing a partial blockade. The failed slope covers an areas of 0.44 sq km. The progressive failure of the slide continued 30th September, 1988. The road could be cleared in 14 days.

Mizoram

The 17th and 18th May 1995 witnessed heavy landslides in Chhimptuipui district of Mizoram damaging a vast tract of land which includes two important townships of Saiha and Lawngtlai, which is the life line for the population of this area. Apart from damage to the road and property, 39 people lost their lives and around 24 people suffered various degrees of injuries (Avasthy & Chakraborty, 1995).

The immature topography of Mizoram having main lithological ingredients of siltstone, shale and subordinate sandstone of Surrna Group of Tertiary age with complex structural disposition, has varying thickness of overburden (02-20 meters). It was subjected to heavy cloud burst on 16th, 17th and 18th May, 1995 which resulted in large scale landslides. The area had also experienced a mild earthquake of magnitude 3.5-4.0 on Richter Scale which aggravated the situation by coupling the landslides which started as slump failure and culminating into debris and mud flows.

The different road sections were also studied and a number of landslides having 5 m and more height along these sections were recorded. Statistically higher incidence of 12.9 landslides per km was observed in Nangpui-Diltang section, whereas one landslide per 3 km was noted in :he Nalkawan Paither section. In this area slump failure is the major cause of the landslide and heavy mud flow along natural water ways has imparted major losses.

The landslide located 7 km from Aizwal (Prasad, 1983), the capital town of Mizoram (Swamy, 1993); had killed 66 persons and destroyed 17 houses. It occurred on 9th August 1992 in early morning hours when the inhabitants were fast asleep. Investigations revealed that the houses were located on the toe of a dip slope made of calcareous sandstone, siltstone and thinly laminated clay-stone. A quarry site located above the village along a road removed the toe support. It is a typical case of planar failure. The downward movement of the failed mass took place along a lubricated clay bearing plane. It is reported that it rained heavily for 2-3 days prior to the slope failure.

Nagaland

The Tuli Paper Mill slide in Nagaland was induced by the Indo-Burma earthquake of 6th August, 1988. The slide affected an area of 4000 sqm. This paper mill is located on overburden material consisting of silt and clayey silt. Prior to earthquake it had been raining heavily in the area. The damage caused by the landslide (Avasthy, 1989) was dislocation of the ground leading to the closure of the operation of the plant for about six months. It involved replacement of several machines. The extent of damages ran into crores of rupees.

Tripura

The hill-slope along which the water conductor system of Gumti Hydro-Electric Project is laid, consists of massive to moderately jointed sandstone and partly weathered and highly disturbed argillaceous sandstone with the intervening shale beds belonging to Bhuban stage of Tertiary age. The sequence is folded into N-S trending anticline. The parts of the water conductor system were damaged by slope failures (Avasthy & Singh 1992), which may be attributed to different causes, such as, dislodgement of sandstone blocks along the adversely oriental valley ward dipping joint planes. The saturation of overburden material and the underlying argillaceous sandstone and shale resulted in multiple surface failure and debris flow. The removal of vegetation cover for ‘Jhum’ cultivation is quite prevalent in the area which accentuates the problem.

An Analysis

The landslides studied in the region are mostly located along the road cuts, besides some in rural and urban areas because the construction of roads has followed the major drainage lines. Large number of landslides have been studied during last two decades and have been categorised in ten types viz (i) Planar failure, (ii) Wedge failure, (iii) Rock fall, (iv) Debris slide, (v) Subsidence, (vi) Minor slip, (vii) Slump, (viii) Creep, (ix) Earthquake induced landslides and (x)Unclassified landslides.

The old landslides at places have been converted into flat ground and have been more often utilised for developmental activities. Hundung Cement Plant in Manipur and Mawnynkhong village in Meghalaya are good examples of this. These places after construction developed extensive creep, resulting in ground distress. The studies carried out have brought to light the causative factors for which remedial measures have been suggested. Kohima in Nagaland and Aizwal township of Mizoram are good examples of how demographic pressure under heavy rainfall mobillised critical slopes in soft formations. The soft sediments, immature topography and complex structural disposition are responsible for the landslides in Mizoram and in the foothills of the Arunachal Pradesh.

In view of the critical slope all along the water conductor system, Reinforced Cement Concrete (RCC) in the cut and cover section was provided to protect this appurtenant structure of Gumti Hydel Project in Tripura. Subsequently however, some unattended reaches of the water conductor system were affected by the slope failure demanding suitable remedial measures.

The unstable conditions under water saturation is the major cause of the slope failure along the rail alignment in Lumding-Badarpur section, Lalabazar-Bhairivi section, Badarpur-Dharmanagar section and Dharmangar-Kumarghat section.

Conclusions

The foregoing description is an illustration of the constraints for the developmental activities as prompted by the landslide hazard in context of the North Eastern Region . Landslides Hazard Zonation considers inherent characteristics like (i) Geomorphology (ii) Geology (a)lithology (b) structure (iii) Hydrology &Climate (iv)Land use (v)Vegetation. It also requires basic: information on (i) regional tectonic setup (uplift) (ii) tilting (iii) faulting (iv) removal of support (natural & anthropogenic) (v) seismic activity (vi) degree of weathering. The expectation of the society unaware of various constraints which are out of landslides hazard zonation; lies in the predictions of (1) spatial and temporal occurrence (2) type of landslide, (3) volume of the mass involved (4) velocity with which mass moves out ward and (5) the distance which will be covered by the moving mass. In absence of the inputs of this information the situation remains hypothetical as far as preventive measures are concerned which are to be adopted along with the developmental schemes.

Mazumdar (1980) attempted a Regional Hazard Zonation Map on the basis of susceptibility to landslides in terms of physico-mechanical properties of rocks underlying the slope and intensity of rainfall.. The disastrous landslides of 1995 devastating the town of Saiha and Lawngtalai leaving 39 dead and 24 sustaining various level of injuries motivated the author (Avasthy

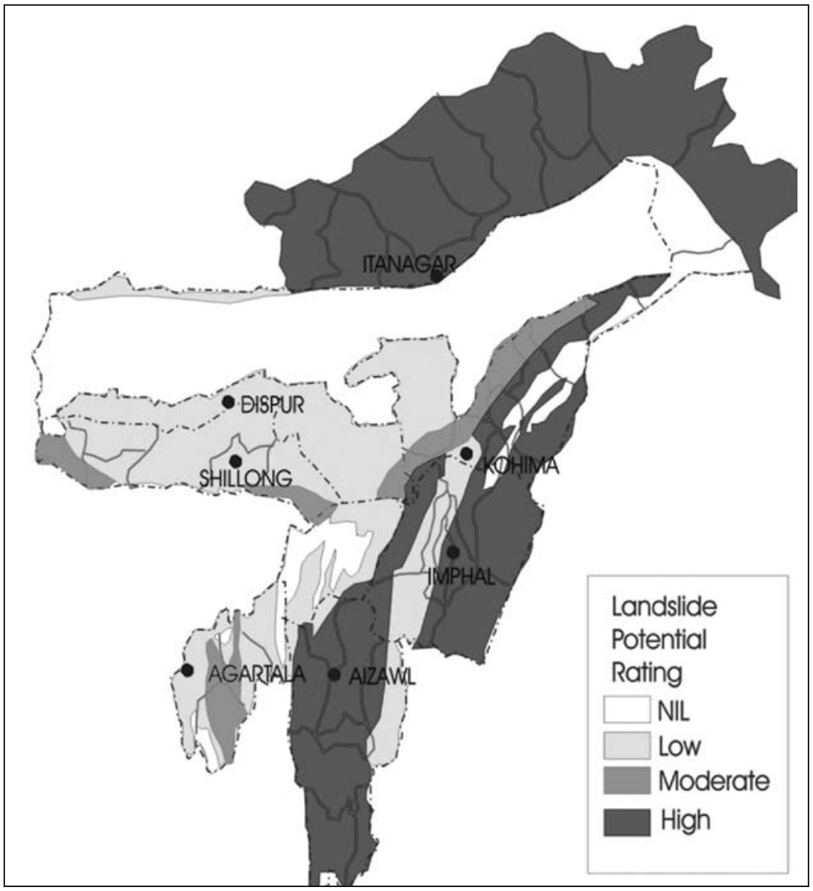

Figure 1: Landslides Hazard Zonation of the North Eastern States

1998) to prepare a modified Landslide Hazard Zonation map on pragmatic inputs of slope characterisation, physio¬-mechnical characteristics of the rock mass, nature of overburden material, intensity of rainfall and above all magnitude of landslide incidences (Figure.1).

The demarcation of landslide hazard zones by using input of landslide incidences has higher degree of rationale and with more efforts this input may lead to better defined zones of landslide potential too. Though societal anxiety can not be silenced by these maps, their mesoscale versions can certainly provide generalised answers to its quarries. The temporal and spatial prediction of landslide still being a far dream, the micro zonation of the areas with higher and moderately higher categories in LHZ maps could provide more accurate answers to some of these quarries.

The disaster management has two basic ingredients; one is identification of the problem in relation to the targeted area(s), and second is working strategy to achieve the higher level of mitigation. But the process of mitigation is dependent on the economics of the cost benefit ratios. Thus under these considerations area are to be identified for implementation of mitigation action plan which can be made possible through these landslide hazard zonation maps.

Such landslide hazard zonation maps would help the planners to make an assessment of the ground conditions for taking up the site specific geotechnical investigation as an essential basic premise to the ground friendly developmental activities. It is recommended that based on such exercise regional zoning laws may be formulated and enforced in the critical landslide prone areas in all the North-Eastern States, which will go a long way in ensuring the safety and longevity of the people and safe civil constructions in the area.

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Earthquake Risk Management in the North East

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Introduction

Apart from the close proximity to each other and breath taking scenic beauty, another common feature of the states in the North Eastern region is their high degree of risk and vulnerability to high intensity earthquakes. The North Eastern Region has experienced 18 large earthquakes (M>7) during the last hundred years including the great earthquakes of Shillong (1897) and Assam-Tibet border (1950) both with M=8.7. Several small and micro earthquakes have also been recorded frequently in the region. The high seismicity in the North Eastern states is attributed to the collision tectonics between the Indian plate and the Eurasian plate in the north and subduction tectonics along the Indo-Myanmar range (IMR) in the east. It is also observed that the lithospheric subduction at the Himalayan belt ceased during Pliocene time and the current shallow seismic activity is the effect of continental collision. Subduction, on the other hand, is still continuing in the Indo-Myanmar Range, which is reflected in the intermediate to deep focus earthquakes occurring in the region.

The high seismic risk and vulnerability in India can be seen from the fact that 10.9% of it's geographical area falls in the seismic zone V which is vulnerable to very high seismic risk, while 17.3% of it's geographical area falls in seismic zone IV vulnerable to high seismic risk. Together, these two zones cover 28.2 % of India's geographical area. According to the Vulnerability Atlas of India prepared by the Building Materials Technology Promotion Council (BMTPC), 229 districts of India fall within seismic zones IV and V. This Vulnerability Atlas has been prepared based on the past trends of earthquakes in the country and efforts are now under way to prepare a probabilistic seismic hazard map for India, with the help of seismic experts and scientific institutions, to more realistically reflect the seismic risk and vulnerability profile of the country.

Given the high seismic risk as reflected in the vulnerability of 229 districts in 22 states and union territories of India, the Government of India has initiated several pioneering efforts to strengthen the earthquake preparedness in the country through a proposed National Earthquake Risk Mitigation Project (NERMP) which is currently getting finalized. This article provides an overview of some of the measures which are being proposed to address the seismic risk in the North Eastern region.

Construction of All New Structures

The high seismic risk in the North East makes it imperative that all new construction of buildings, public infrastructure, amenities and assets coming up in the region will have to strictly comply with the codal provisions of the National Building Code 2005, relevant earthquake-resistant building codes and other safety codes. The officials responsible for scrutinizing building plans and granting building permissions have to be made aware of the existing standards and codes which have to be followed while carrying out the construction of structures in high and very high risk zones. The grant of bank loans for the construction of any new structures has to be made contingent on the compliance certificate issued by a competent structural engineer that the design of the structure has incorporated the necessary earthquake-resistant features as mandated by the National Building Code 2005, relevant earthquake-resistant building codes and other relevant safety codes.

Review of Safety of Existing Lifeline structures

A large number of existing non-engineered building stock may have been constructed by private builders and masons who may not have the necessary technical skills to construct earthquake-resistant buildings. Even in the case of masonry structures and reinforced cement concrete constructions, it is likely that adequate attention may not have been paid to the structural safety of the buildings to withstand high or very high intensity earthquakes. It is necessary for the district administration to identify critical lifeline infrastructure and public assets and carry out structural safety audit of such structures with the guidance of trained technical personnel. Wherever it is felt that the structures are weak and fragile and cannot withstand high or very high intensity earthquakes, a priority list of such structures has to be drawn up by the district administration and their seismic strengthening and retrofitting taken up with the support of state government resources. NDMA, in collaboration with the state governments, has proposed the selective retrofitting of a few selected district hospitals from the North Eastern states and a few selected schools from selected districts from seismic zones IV and V from the North Eastern states.

Capacity Building of Technical Personnel

The engineers, architects, lead masons and masons engaged in the construction industry will have to be provided with the skills and knowledge on earthquake-resistant construction techniques, structural safety audit of existing critical lifeline structures and seismic strengthening and retrofitting of weak structures. NDMA has initiated the preparation of a National Earthquake Risk Mitigation Project (NERMP) in collaboration with state governments in high and very high risk seismic zones IV and V. Capacity Building of Technical Personnel is one of the most important activities envisaged in this proposed project, by involving the Indian Institute of Technology, Guwahati, selected engineering colleges and architecture colleges, and selected Industrial Training Institutes and Polytechnics in the North Eastern states. The course curriculum has been finalized with the help of technical experts from the IITs and Indian Institute of Architecture. These training programmes, when conducted as a part of the national initiative, will improve the capacity of technical personnel in the construction industry to undertake earthquake-resistant construction in the North Eastern states and to carry out seismic strengthening and retrofitting of critical lifeline structures to enable them to withstand high intensity earthquakes in future.

Public Awareness on Earthquake Risk and Vulnerability

All stakeholders need to have greater awareness on the earthquake risk and vulnerability in the North Eastern states, as an aware community is better prepared to face earthquakes when they occur and to minimize the loss of lives, injury and loss of assets, property and infrastructure through their conscious actions. NDMA, in collaboration with the state governments and State Disaster Management Authorities, proposes to launch intensive public awareness campaigns on earthquake risk and vulnerability in earthquake-prone areas, using electronic and print media as well as street plays, hoardings, wall paintings, etc. Special campaigns will address youth in educational institutions and children in school going age group to disseminate the public awareness messages among their neighbourhood communities. In the event of the sudden occurrence of an earthquake, the local communities must have the basic skills of search and rescue, evacuation, establishment of temporary shelters, emergency first aid, distribution of relief to the affected households, etc. Village level disaster management task forces have been set up in several villages to carry out tasks like search and rescue, first aid, shelter management, relief coordination, needs & damage assessment, distribution of relief, water & sanitation in the disaster-affected villages, trauma counseling, patrolling, and disposal of dead bodies and animal carcasses, etc. The public awareness campaigns will be supported by other stakeholders like corporate sector, non-governmental organizations, faith-based organizations and community based organizations like mahila mandals, yuvak mandals, self help groups, etc.

Regulation and Enforcement of an Appropriate Techno-Legal Regime

In the developing countries, weak compliance of building codes and town planning byelaws and inadequate attention to enforcement and regulation are resulting in the loss of lives, injuries and loss of property when earthquakes strike. In the developed world, even a high intensity earthquake causes minimal loss of lives and property as the construction of buildings, public infrastructure and amenities in these countries is governed by strict regulations which ensure public safety. Thus, a high intensity earthquake in the United States of America or Japan may not lead to the loss of lives of a large number of people because the compliance with a rigorous techno-legal regime will ensure that few buildings will collapse resulting in low loss of lives. Even in the developing countries, recent earthquakes have shown that while the buildings constructed in strict compliance with earthquake-resistant building codes and other safety regulations have been able to withstand the impact of the earthquakes, poorly constructed buildings in the same neighbourhood have collapsed resulting in loss of lives and destruction of property and assets.

We have often heard the saying: “Earthquakes don’t kill; collapse of buildings does.” The enormous loss of lives and injury to people can be minimized by the strict compliance and enforcement of an appropriate techno-legal regime which consists of modified town planning bye-laws, earthquake-resistant building codes and other relevant safety codes, building bye-laws, National Building Code 2005, Development Control Regulations, etc. in the jurisdiction of the Urban Local Bodies and their extension to semi-urban and rural areas under the jurisdiction of various local administration agencies. The rigorous enforcement of a techno-legal regime is a sine-qua-non for the creation of an enabling environment which assures the safety of it’s citizens in disaster-prone areas.

Institutional Capacity Development

With the active involvement of the State Governments, the Government of India will strengthen the institutional capacity in the North Eastern region in the field of disaster management. This will include strengthening of the Communication network and network of seismic monitoring stations in the North Eastern region, improving the scientific capability of science and technology institutions, academic, professional and research institutions in the region, incorporation of disaster management in the curricula of educational institutions and professional and vocational institutions, support to research and development initiatives and documentation of coping strategies and good practices and their wide dissemination in earthquake-prone areas.

Improved Emergency Response Capacity in the Region

The Government of India has deployed a well trained and well equipped battalion of the National Disaster Response Force (NDRF) at Guwahati for the North-Eastern states. Specialised teams of this battalion have also carried out familiarization visits in the various North-Eastern states and interacted with state government and district administration officials and conducted community capacity building sessions. State Governments have been advised to establish State Disaster Response Force (SDRF) units from their existing police force and such forces will be trained and equipped with life saving equipments purchased with 10% of the Calamity Relief Fund allocations to the states. The volunteers of the Indian Red Cross Society chapters, Nehru Yuvak Kendra, National Social Service, National Cadet Corps, Home Guards and Civil Defence, etc. will be trained to carry out specific disaster management related tasks to assist the district administration. Elected representatives of the Panachayati Raj Institutions will also be encouraged to play an important leadership role in coordinating the disaster management efforts at the local levels.

Conclusion

The enormous investment outlays for strengthening the road network, rail network and air transport network for the North Eastern region proposed for the Eleventh Five Year Plan period and the development of urban infrastructure and amenities through the Jawaharlal Nehru National Urban Renewal Mission (JNNURM) projects and the proposed new public infrastructure and amenities in the region will have to be designed with special attention to the earthquake risk and vulnerability in the region. Simultaneously, there is a greater need to strengthen the medical preparedness and mass casualty management facilities in the region by planning the procurement of helicopter ambulances, containerized mobile field hospitals and integrated ambulance network. The public awareness on earthquake risk and vulnerability will become the foundation for an enlightened multi-stakeholder initiative to launch a concerted attempt to usher in a culture of preparedness, mitigation and improved emergency response in the North Eastern Region. The National Disaster Management Authority of the Government of India and the North East Council will work in close cooperation with the Ministries and Departments of the Government of India and the state governments of the North Eastern states to work towards the vision for a "Disaster Resilient North East " which puts the safety of it's citizens, disaster-resistant capability of the critical infrastructure, public amenities and assets as well as improved community resilience among disaster-prone communities as it's foremost objectives.

Earthquake Disasters in the North Eastern Region
The Malady and the Emedy

P P Shrivastav
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The Malady

The North Eastern Region (NER) of India is seismically one of the most active intra-continental regions of the world. Seven out of the eight States in our NER fall in the maximum seismic vulnerability Zone-5; only Sikkim (included as a Member of the NER family in 2005) is in Zone-4. In fact, Northeast India was identified (Honolulu Workshop : 1978) as one of the six most earthquake prone areas of the world, the other five being Mexico, Taiwan, California, Japan and Turkey. As many as 995 Earthquakes (EQ) of varying intensity were recorded during the five years (2001-2005) in the NER. Tremors from 26 EQs of intensity 7 and above have been felt in the NER over the 113 years after the devastating Shillong EQ of 1897. (Appendix-1)

Geological Evolution of NER

The reason behind such high frequency of EQs in NER lies in the geological evolution of this part of our country. Till about 65 million years back practically the entire NER was a sea-bed. Gradual northward drift of the Indian Plate and its collision against the Chinese Plate in the North and the Burmese Plate in the East, resulted in upward thrusts giving birth to the Himalayan range in the North and the Axial Ridge along the Indo-Myanmar border in the East. Substantial quantities of sediments started flowing downhill and getting deposited in the lower reaches raising the level and resulting in delta formation and causing the sea to recede southwards. This deltaic environment persisted for around 10 million years resulting in heavy sedimental deposits in areas that now constitute the Upper Brahmputra Valley. Around 15 million years back fresh seismic activity caused re-incursion of sea for a couple of million years but with further rise of the Himalayan range in the north and emergence of Shillong and Mikir Plateaus towards the south, the sea receded fully into the Bay of Bengal and the fertile Assam Valley was formed. In course of time, the plant, animal and mineral material that had got buried under the heavy sedimental deposits turned into the rich coal, oil and minerals deposits of the present times. The rivers earlier draining directly into the sea waters became tributaries of the Siang that emerged as the main channel, now called Brahmaputra, which took its shape according to the contours of the Valley.

The continuing geological process of collision of plates and the resultant upward thrust has been causing instability and seismic activity. Fortunately for us, the deposit of soft belt of sediment along the Indo-Myanmar border on the Nagaland-Manipur side functions as shock absorber that saves our adjoining areas from severe damage from the intense seismic activity and numerous earthquakes occurring on the Myanmar side of our border.

The 3 active Earthquake Belts of the world

Experts have recognised 3 major Earthquake belts that account for almost 95% of EQs in the world. These are the Circum-Pacific Seismic Belt, the Alpide-Himalayan Seismic Belt and the Mid-Oceanic Ridges Belt. "The second most active Alpide-Himalayan Seismic Belt starts from South-East Asia near Java Sumatra, continues through Andaman & Nicobar Islands, India-Burma border regions, swings through north of India in the foothills of Himalaya and then moves west through Iran into Greece and Italy." (Dr Harsh K Gupta). There are also a number of geological Faults and Thrusts which are weak spots scattered across NER, as shown in the map below.

Earthquake – the deadliest natural disaster

EQs are responsible for more casualties and damage than any other type of natural disaster. As per the World Disasters Report 2010, persons killed by the 290 EQs during the decade (2000-2009) and Tsunamis/Landslides/ flooding etc triggered by them stood at the staggering figure of 4,53,553 and the estimated damage added up to US $ 183,425 million (at 2009 prices).

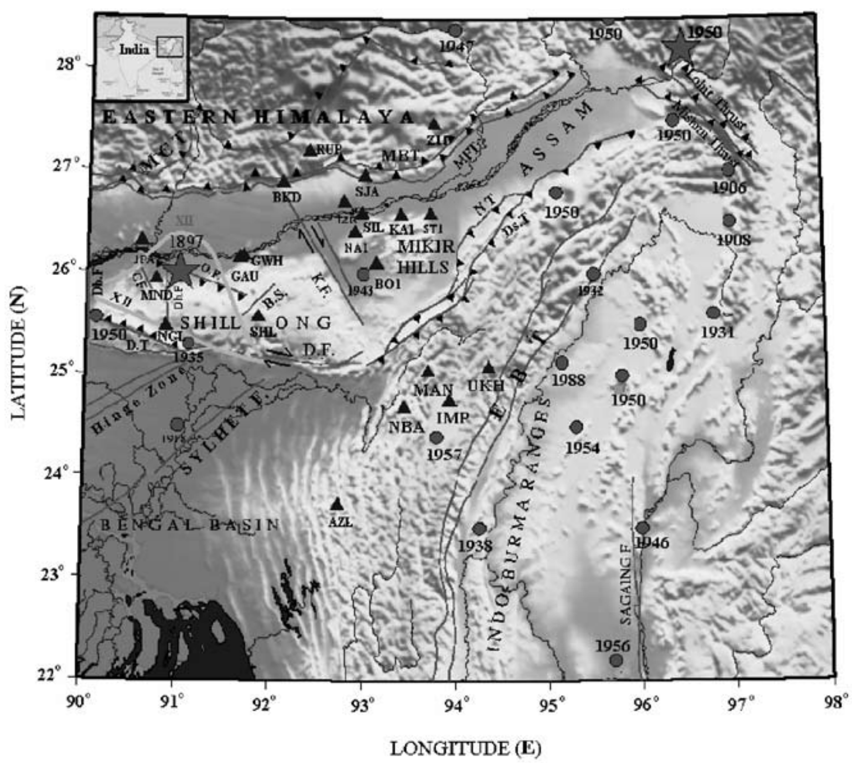
Big killers: not EQ by itself but EQ-triggered phenomena,

Since our prime concern is to prevent and minimize loss of life, let us analyse the precise factors that actually kill and injure people and damage property and public assets. It is interesting to note that EQ by itself hardly kills directly. Death, injury and damage are caused mainly by collapse of buildings and structures, by induced landslides causing similar damage of life, communication network etc; flooding arising from bursting of dams or blockage of waterways by EQ-triggered landslips (as had happened in Assam in 1950-EQ); or crippling damage to vital public utilities. Each of these causative factors has to be studied and neutralised as effectively and urgently as possible. This would require serious, purposeful and sustained risk-reduction effort well in advance.

EQ-triggered Collapse of Buildings is a major killer

Loss of life is the maximum in areas where population concentration is high like in urban agglomerations. The situation gets further compounded when buildings are constructed in a haphazard and unplanned manner without consideration for tremor-resilience and without proper street pattern to permit movement of Emergency Relief & Rescue vehicles in emergencies. This unfortunately is the state of affairs in most of the old towns in the NER and they are highly vulnerable.

Tectonic Features of the North Eastern Region Showing major EQs, Thrusts, Faults and Shear Zone



Legend : STARS : 2 Great EQs (M > 8.0) of 11879 & 1950; **CIRCLES :** Large earthquakes (7.0 to 8); with years of events. **BLUE TRIANGLES :** Digital Seismic Stations; **HAT SHAPED LINE :** Isoseismal XII (MM), of the 1897 Shillong EQ. **MCT:** Main Central Thrust; **MBT:** Main Boundary Thrust; **MFT:** Main Frontal Thrust; **DF:** Dauki Fault; **DT:** Dapsi Thrust; Dh.F: Dudhnoi Fault; OF: Oldham Fault; CF: Chedrang Fault; BS: Barapani Shear Zone, KF: Kopili Fault, NT: Naga Thrust, **DsT:** Disang Thrust and EBT:Eastern Boundary Thrust.
(With grateful acknowledgement to J.R.Kayal, S.S.Arefiev, S.Barua, D.Hazarika, N. Gogoi, A.Kumar, S.N.Chowdhury and S.Kalita for their article in CURRENT SCIENCE, July 2006)

Model Building Codes for seismically resilient structure (formulated by experts) had been circulated among the States at the initiative of NDMA. The question is whether these have been notified and enforced and if so are these being sincerely implemented. This is important since the general attitude even among the literate, well-to-do sections is to 'manage' things in such a way that all formalities are satisfied and regulations complied with "on paper".

The last 2 Major EQs (8+) struck NER at an interval of 53 years, the Shillong EQ in 1897 and the Assam EQ in 1950. Sixty years have gone by since then and apprehensions of recurrence of a similar calamity are rife. One shudders to think of the likely consequences, God forbid, of such an occurrence in the vicinity of a big town. An idea of what could happen is given below.

Lessons to be learnt from two recent EQs in Haiti and Chile

An eye opening example of the large extent to which life and property can be saved by advance preparation can be vividly seen from the following factual account of two very recent EQs of comparable magnitudes, one in Chile and the other in Haiti.

An EQ of magnitude 7.0 struck Haiti in the afternoon (16:53 hrs local time) on 12 Jan 2010. 250,000 residential and 30,000 commercial buildings were reported to have collapsed or severely damaged and needing demolition. Early estimates put the death toll at 2,30,000, the injured at 3,00,000 and those rendered homeless at 10,00,000. (However, a subsequent investigation by Radio Netherlands questioned the official death toll and reported an estimate of 92,000 deaths as being a more realistic figure (which is enormous enough).

Compare this to a stronger EQ of magnitude 8.8 Mw that struck Chile just 45 days later on 27 Feb 2010 at 03:34 local time, a time when most people are expected to be in bed at home. It was strongly felt in six regions inhabited by around 80% of the country's population. 3,70,000 homes were affected and death toll as per the early reports was only 802. Later the actual identified death toll was reported to be 486.

The only difference was that in Chile Town Planning and Building Codes had been adhered to, the towns were well-planned and the buildings were EQ-resilient: most did not collapse. That saved precious lives and limited the extent of damage.

As Roger Bilham writes (Nature: Feb 2010) in his article Lessons from the Haiti Earthquake, on the basis of site-study, "..the reason for the disaster was clear in the mangled ruins – the buildings had been doomed during their construction. Every possible mistake was evident: brittle steel, coarse non-angular aggregate, weak cement mixed with dirty or salty sand, and the widespread termination of steel reinforcement rods at the joints between columns and floors of buildings where earthquake stresses are highest…. The death and injury of about 15% of more than 2.5 million people in Port-au-Prince and its urban agglomeration, and the roughly 1.5 million people now homeless, is a consequence of many decades of unsupervised construction permitted by a Government oblivious to its plate boundary location….."

The Haitian example has a strong message for us in the NER where the situation is qualitatively not very different. High-rise steel-and-concrete structures (with little regard to seismic considerations) have come up in urban agglomerations alongside old weak buildings. Implementation of Town Planning Regulations and Building Codes even where they have been updated with seismic considerations, is weak. The situation particularly in capital towns of hill-States is highly perilous. The Haiti example has thus a strong message for us in the NER since implementation of the Model Building Codes (incorporating EQ-resilience angle) circulated by NDMA quite some time back (if at all brought into force) leaves much to be desired. There is not a day to lose in going all out to commence remedial measures and prevent this scale of damage in our region.

Havoc by EQ-triggered Landslides and blockage of waterways

Landslides triggered by EQs pose a danger to hillside habitations. Sometimes such landslides block waterways and unless the blockage is cleared urgently, the bursting of this blockage by pressure of accumulated water would cause havoc. It was such a landslide triggered by the great Assam Earthquake of 1950 that blocked the river and the waters finally burst out with tremendous force. The resulting deluge washed away all that lay in its way, including the Sadiya town and parts of Dibrugarh. Such phenomena might also have been responsible for the unbelievably large loss of life in a few notable EQs in the past, viz.,

Date	Region	Deaths
27 07 1976:	China – Tangshan	2,42,000:
16 12 1920 :	China – Kansu	1,80,000
28 12 1908 :	Italy – Messsina	1,20,000 Messina & Regio razed to ground
07.09.1303:	China- Shanxi	8,30,000 Probably the greatest known natural disaster

Landslides need to be given more focused attention

EQs have the effect of triggering off dormant and potential landslips and this is a big potential threat to life, property and public assets. Some of the items flagged in the First Indian Landslides Conference (Lucknow: 01-02 Nov 10) merit serious consideration. These include the following:

i. periodic updating of the inventory of all active landslides and need for networking and free exchange of information/data among all the concerned agencies.
ii. Close monitoring of active landslides that threaten human settlements and pose a risk to life, property and important public assets.
iii. Studies on landslides and relentless R&D efforts to enhance predictive and advance warning capabilities.
iv. Listing of passive Landslide sites likely to be triggered off by events like Earthquakes etc
v. Public awareness programmes on Landslides and Do’s & Don’ts with involvement of students, PR functionaries and NGOs.

EQ Forecasting capability is still being developed

While the phenomenon of build-up of energy deep below the surface of the earth leading to EQs is generally known to our scientists, the ability to modulate the same to our advantage, to defuse the fury or divert them to safer locations is still beyond reach. In fact, we seem to be largely helpless even in making short-term forecasts of place, time and magnitude of likely EQs with reasonable and acceptable degree of accuracy and precision.

In medium-term forecasting, appreciable success has been achieved by our eminent world famous Seismologist Dr Harsh K Gupta, Pannikar Profesor, (formerly Secretary (Ocean

Development), Director, National Geo-physical Research Institute Hyderabad and Professor, University of Texas). He along with his colleague Dr Singh, after deep study of seismology of NER, made (1986) a forecast that an earthquake of likely magnitude of 8+0.5 with focal length between 10-40 km in the specific area bound by Latitude 21 to 25.5 degrees N and Longitude 93 to 96 degrees East in NER, was likely to occur anytime between 1986 and 1990. This forecast did come true and an EQ of 7.5 magnitude did occur in the area (25.12 N and 95.17 E) at a depth of 115 km on 06 Aug 1988.

One notable instance of successful Long-term forecasting is that of the HAICHENG EQ (7.3) in China that occurred on 04 Feb 1975. The forecasting exercise was conducted in 4 stages. The first warning (of an EQ in 1-2 years) was issued in 1974. Intensive studies continued and prediction of EQ in first half of 1975 was issued on 28.1.75 following observation of animal, hydrological and electromagnetic precursors. In the 4th stage following 2 foreshocks of 4.7 and 4.2 intensity on the early morning of 4.2.75 full red alert was declared and the people were evacuated from the danger zone. The predicted EQ did occur at 19:36 hrs on the 4th February itself. As per estimates around 1,00,000 lives were saved by this successful forecast of this EQ and immediate follow-up action to evacuate the residents with the help of the military.

Scientific Study of EQ-Precursors

The mighty upheavals below the ground which burst out overground with earth-shaking intensity in the form of EQs, cannot but give out some tell-tale signs during their long building-up phase. The fact is that warnings are very much there and animals perceive them and show visible signs of panic. Our tribal communities in the Nicobar Islands could intuitively sense the danger and took to high ground which saved their life from the fury of the tsunami in 2004. On the other hand, the ‘advanced’ communities and establishments in the nearby Andamans were taken totally unawares and suffered serious damage. Unfortunately, the so-called ‘advanced’ people/ societies have lost the God-given gift of the faculty of intuition and intuitive perception. That way our communities in NER are at an advantage: only we have to give due importance to their indigenous wisdom and traditional coping practices.

Dr Arun Bapat, an eminent and dedicated seismologist-researcher, in his researches examined animal and human precursors and made some significant and interesting observations. In his studies of some recent EQs e.g., Latur (1993), Bhuj (2001), A&N EQ-triggered Tsunami (2004) and Kashmir (2005), he observed the following:

- Spurt in number of OPD-patients 5-7 times the average, 10-15 hours before EQ (especially in problems of psycho-somatic origin (like blood pressure, heart trouble, headache, migraine, respiratory disorders, restlessness etc.)
- Number of deliveries went up 3-5 times the average on the penultimate day of EQ and to 7 times the average on the day of EQ.

These are useful inputs that can serve as useful pieces of information which when examined along with relevant data in respect of other known precursors (OLR/ Hydro/Thermal/Electromagnetic and others), collected by a number of scientific/academic institutions and researchers from different locations and transmitted in real-time to a Regional Data Collection and Decision Support Centre and studied by multi-disciplinary team of experts, can give authentic forecasts that could result in saving of invaluable lives and valuable property and public assets. Further studies and research are needed.

NEC has also initiated some studies and researches jointly with NEIST. These are going to be expanded substantially by mobilising academicians in the Universities known for their work in this field and other eminent scientists and researchers known for their work on EQs and EQ-precursors. This programme will be coordinated, supervised and monitored by a core monitoring team of top-level experts on the subject in the country. Dr Harsh Gupta's guidance has been sought in this regard. We are hopeful of breaking new ground in this field that will enhance reliability, accuracy and precision of our forecasting capability in the coming years.

Contours of the malady have been given above and now let us deal with the remedy in the following section.

The Remedy

(a) Achievements so far

Paradigm shift in DM Strategy: Pre-disaster Risk Reduction and Mitigation

Enactment of the Disaster Management Act 2005 and the setting up of the National Disaster Management Authority (NDMA) chaired by the Prime Minister himself, have brought about a paradigm shift in Disaster Management (DM) strategy. The emphasis on post-disaster Relief & Rehabilitation prevailing since the old colonial days has now been shifted to Pre-Disaster Risk Reduction and Mitigation.

Mandate to the Ministries/Departments

Ministries and Departments of the Central Government are now mandated by the DM Act to prepare disaster management plans (sec 37). The State Governments have to integrate into … development plans and projects, the measures for prevention of disaster and mitigation; and to allocate funds for mandatory responsibilities have been cast on the States also.

Implementation machinery: NDMA, SDMAs & DDMAs

The machinery to plan and implement the new DM strategy, viz., the National Disaster Management Authority (NDMA) at the Centre under chairmanship of the Prime Minister and the State Disaster

Management Authorities (SDMAs) under the chairmanship of the Chief Ministers, are in place and functional in all the States. The machinery permeates down to the District level in the shape of the District Disaster Management Authority (DDMA) in each District chaired by the Collector/ District Magistrate/Dy Commissioner.

Comprehensive guidelines have been prepared by the NDMA on dealing with various types of disasters. These have to be followed by all concerned in te manner and to the extent considered relevant for the local conditions and situations which will differ from place to place and time to time.

Need for a Regional approach in NER: Role of NEC

Geo-climatic and topographical factors in NER are such that DM Plans of individual States of NER are likely to prove inadequate unless closely integrated with those of neighbouring States and of Assam through which most of the inter-regional and intra-regional communication links traverse. Therefore, one of the first tasks taken up by us in NEC (reconstituted in Mar 05 as the Statutory Planning Body for the 8 States in NER) was to formulate a Regional Framework for DM in close consultation with NDMA. These are suggestive and implementation is left to the State DM machinery. The points flagged in the Regional Framework inter alia include the following:

(i) Compilation of Authentic Data-base & Coordinated R & D Studies under competent supervision/monitoring)
(ii) Microzonation/Vulnerability Mapping:
(iii) Develop Predictive and Advance warning Capability:
(iv) Mass Awareness Campaign
(v) Capacity Building of the various Stakeholders on subjects that may include the following:
  - Skilled knowledge on seismic risk, vulnerability and Quake-resilient structures
  - Preparedness and Response skills relevant to the area/risk/situation;
  - Retrofitting of existing buildings/structures (especially of Lifeline structures)
  - Modified Town Planning Regulations and Building Bye Laws and need for massive Training Campaigns for all those involved in constructions

Stages in capacity building may include:

a. Preliminary sensitisation:
  - Concerned State Govt functionaries (especially PWD & Urban Dev Dept) mainly at State Hqs.
b. Training of Key Resource Persons (KRPs) as Master Trainers
  - Professionals, especially Engineers and Workers (in both Public & Pvt Sectors) engaged in construction works;
  - Engineering Colleges, IITs etc;
  - University (relevant Depts); Senior students in HS Schools;

- PRIs, Youth and Women's organisations in towns and villages;
  (First-level courses to be organised by NDMA/NEC. Thereafter SDMAs would organise further training courses step-by-step downwards with the help of these trained resource persons. Every Gram Panchayat may have 6-12 Civil Defence Volunteers - Gram Rakshaks - trained in DM/DRR/Relief duties).

c. Carrying forward by SDMAs of training programmes on a continuing basis with assistance of these KRPs.

(ii) Advance Disaster Risk Reduction measures - Preparations on the Ground:

a. Fail-safe Emergency Communication System (to reach warnings of impending Disasters up to Village level without loss of time) and Digital Tele-Health Disaster Network for NER (to reach expert medical/para-medical services to the affected people in emergency situations).

b. Human Infrastructure: Organise Gram Rakshaks – Volunteers under Civil Defence Organisation as suggested by NDMA, at Gram Panchayat level, trained in DM/DRR/Relief functions.

c. Material Infrastructure for Disaster Risk Reduction-cum-Relief

d. Study of specific Landslide sites at important locations (e.g., on arterial roads that disrupt communications year after year) by acknowledged experts

Substantial progress has been made by them in respect of the different types of disasters relevant to them. These are not being touched on in this paper in the interest of brevity, since representatives of SDMAs participating in the National Conference will no doubt be including up-to-date progress under various heads in their presentations. What generally merit focused attention are all the possible and feasible ways to neutralise the killer-factors of EQs as mentioned earlier. Meanwhile a move has been initiated for setting up of NE Regional Disaster Management Decision Support Centre (NERDMDSC) at NESAC (to begin with) to provide single-window service to State DMAs for all types of disasters.

The Road ahead

Highest priority to vulnerable buildings/structures

- Pressure has to be built for updating Town Planning Regulations and Building Bye-laws, their strict implementation and retro-fitting of vulnerable structures especially life-line buildings like hospitals etc.

Mass Awareness Campaigns

- State-level public awareness campaigns with talks by experts, exhibitions and demonstrations;

- Reaching School-students and teachers (A programme of regular telecast of DM-oriented modules over the EDUSAT Network is being worked out jointly by NEC/State Govts/NDMA/ISRO with NESAC playing the key role. It is due to commence shortly in Meghalaya on pilot basis, to be followed soon in other States.)

NEC, in its Regional Disaster Management strategy, has emphasized inter alia the need for inter-state coordination among the State Disaster Management Plans of the NE-States with their neighbouring States. Geo-climatic and topographical factors in NER are such that DM Plans of individual hill-States of NER are likely to prove inadequate unless closely integrated with those of neighbouring States and of Assam through which most of the inter-regional and intra-regional communication links traverse. This Conference is expected to consider this issue also.

Ensuring safe new buildings and retrofitting of old unsafe structures

Several more questions also arise, like whether all the concerned architects and engineers are trained in EQ-resilience techniques in new constructions and retrofitting of old ones to make them resilient (since this is a comparatively new development); whether the Junior Engineers, supervisors and masons have been put through appropriate training capsules, since most of houses in rural areas and small towns are not engineered but built by masons. NDMA has been stressing these points and it is for the State Disaster Management Authorities (SDMAs) to place them high enough on their priority list.

Given these ground realities perhaps the most effective way to get these life-saving regulations implemented on the ground in letter and spirit than merely on paper, is to spread public awareness of the dangers that non-EQ-resilient structure pose not only to those living within but also to their neighbours. Experience shows that students are the most effective agents to carry the message across the board since they permeate all sections of the society. One may decide in favour of saving some money by not taking expert advice, but may not be able to disregard plea of his own young son or daughter to ensure that their house is made EQ-resilient to save lives of family-members as well as of neighbours in the adjoining buildings.

NEC jointly with NDMA and State Govts has been organising 2-day State-level Disaster Management Workshops with personal participation of the Chief Ministers, in five States so far for creating awareness and preparedness. Also a pilot programme of utilising EDUSAT network for telecasting Disaster-related modules specially designed for creating awareness and knowledge of do’s and don’ts among School students and teachers. NESAC (North Eastern Space Application Centre) a joint-venture of ISRO and NEC, has been playing the coordinating role in this endeavour. It is proposed to be introduced first in Meghalaya on a pilot basis and thereafter in other States in a phased manner. Unfortunately, EDUSAT coverage is limited only to a fraction of Schools in the States. Special programmes will, therefore, have to be organized on a large scale with the help of teachers, NGOs and others to cover the entire student-population and Municipal/Panchayati Raj functionaries.

In this context, it may be relevant to invite reference to a recent (Oct 2010) Report brought out by the World Bank titled It is Not Too Late : Preparing for Asia's Next Big Earthquake. While the focus of this Report is on Phillipines, Indonesia and China, it cites a 'best practices' example of the Istambul Seismic Mitigation and Emergency Preparedness Programme (ISMEP) as an example of a successful and on-going earthquake risk management programme.

Conclusion

To sum up, the roadmap for saving life and property in the event of earthquake would include:

i) Making new structures earthquake resilient and retrofitting the old and week structures.
ii) Training of engineers right up to the level of masons.
iii) Orientation programmes for policy-makers.
iv) Sincere and effective public awareness campaigns specially for students and NGOs on large sale
v) Popularizing simply dos and don'ts as advised by authorities.

Discussions, exchange of views and of the best-practices followed in different States on these and other relevant issues in the forthcoming National Conference will no doubt prove to be of great value. However, the experiences in a democratic set up like ours has been that success of any such programme would depend on public awareness and mobilistion of strong public opinion in favour of steps aimed at investment of some time, labour and money for substantial long term gains of saving invaluable lives and valuable property. Mere issue of orders by the authorities does not take us far. In this context, awareness drive amongst students is expected to yield the best result since they permeate all sections of the society/community and have the knowledge and enthusiasm.

Strategic Issues and Raod Map

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Every year seismic observatories record about two hundred earthquakes of varying intensities with epicenters in or around the North Eastern Region of India. Most of these quakes do not cause any damage and generally go unnoticed, although the cumulative effects of such a large number of shakes on the stability of the hilly slopes and soil erosion has escaped serious scientific investigations. On an average 1.3 earthquakes every year are recorded 6+ in the Richter scale and each one of these could be potentially dangerous if this had shallow depths or located near human settlements. Big earthquakes with intensities 7+ return once in 16 years in the region and mega earthquakes of 8+ have a return period of 50 to 60 years.

The North East had two recorded mega earthquakes – the 8.7 earthquake of 12 June 1897 in the Shillong plateau and Independence Day earthquake of 1950 of same magnitude in Tibet-Arunachal border. The 1897 earthquake had killed 1540 persons, injured lot many and damaged houses and infrastructure over wide areas extending upto Dhaka and Kolkata. The 1950 earthquake killed a minimum of 1500 people and triggered a large number of huge landslides that dammed many tributaries of Brahmaputra and changed the course of the river itself. Large areas of the river valleys were flooded; tracts of fertile agricultural land became parts of river bed while many areas irrigated by river water became dry. This has had long term impact on environment and livelihood of the people in the region.

Earthquake Risk Assessment

While volumes have been written on earthquakes of the North East Region, comprehensive scientific assessment and analysis of the risks of earthquake in the region in both qualitative and quantitative terms is yet an unfinished task. Geologists and seismologists have generally mapped the earthquake zones and identified the main fault lines, but current status of the fault lines and probable future rupture points are largely not known. As Dr. D.R.Nandy has pointed out in his paper in this volume 'many questions concerning the exact location and nature of earthquake sources based on contemporary tectonics have remained largely unsolved'. The prediction of the Manipur-Burma border earthquake of 6 August 1988 had created hopes of similar predictions, but further research pointed enormous complexities of such predictions and in fact the future of earthquake predictions still remains nebulous. This is true not only of the North East but of other regions of the world as well including the most advanced countries. Microzonation of two cities in the North East had been completed but there are large areas of very high risks where similar studies are yet to be taken up. All these gaps in our existing knowledge and understanding of the hazards of earthquake in the region definitely call for a more focused, sustained and time bound multi-disciplinary research agenda and provisions of state-of-art infrastructure and necessary investments for pursuing the agendas under expert supervisions.

If our understanding of earthquakes of the region is still ad hoc, our knowledge of the vulnerabilities of the earthquakes is even more incomplete. Our Census data does give good ideas of the settlement pattern in urban and rural areas and the type of dwelling houses in which people live. But the building typologies captured in our census do not give us definite clues about the seismic strength of either the old or the new structures. The 2001 census, for example, registered a total of 90.28 lakh dwelling houses in the North East with average occupancy of 4.3 persons per house, but the foundation, age or other parameters of seismic strength of these structures are not captured and no other alternate data sources are available on the basis of which any realistic assessment of seismic vulnerability of these structures could be assessed scientifically. This again calls for more research into the vulnerabilities of built environment.

The Vulnerability Atlas of India relied on the census data to conclude that 8.9 lakh houses made of mud and unburnt brick and 46 thousand houses with stone wall in the North East very highly vulnerable to earthquakes, while 13.8 lakh burnt brick houses have high vulnerabilities. It is a matter of conjecture how these buildings would behave during earthquakes. One redeeming feature of the North East is that nearly 66% of the dwelling houses in the region are made of bamboo, thatch or other light weight materials which may collapse during earthquakes but not kill many people. The poor economic conditions of the people have in fact been blessings in disguise. The indigenous communities in the region have very sound knowledge about the strength of locally available building materials and expertise about designing structures with such materials which are not only cost effective but resistant to the shaking in many big earthquakes. There is a definite need for further knowledge and research on indigenous housing design and technology and strengthen them further to make them withstand strong ground motion.

Census data reveals that more than 3 lakh houses in the North East are made of concrete walls. Most of these do not conform to the earthquake resistant building norms. Many of these houses are constructed on dangerous slopes. Structural engineers have apprehensions that many of these structures may not withstand the shocks of even minor earthquakes. Unfortunately numbers of such vulnerable structures are on the rise and in some cities like Aijwal, Itanagar etc these are in fact dominating the urban landscapes. These have been further compounded by the increasing number of multi-storied structures that flout the norms of basic safety and seismic standards. The photo interpretation of the vulnerable structures in the capital cities of the North East at the end of this volume by Dr. Chandan Ghosh would demonstrate the risks that are being added unabated in the urban areas of the North East just as in other parts of the country.

Engineered public buildings in the North East built according to 2002 BIS codes would definitely withstand the shocks of earthquakes, but most of the public buildings were constructed prior to the introduction of the codes and their current seismic strength are not known. Similarly many buildings like schools, community centres, dispensaries etc were constructed through the rural development department or communities which do not generally apply seismic standards and most of these structures are highly vulnerable in earthquakes. We do not yet have good knowledge about the safety of the schools and hospitals which become very critical during and after the earthquakes. We further do not have assessment of the structures of crucial administrative buildings like the police stations, tehsil offices or district headquarters that would play important role in post disaster situations.

North East still does not have good infrastructure like roads, bridges, railways, airports, power projects, communication networks etc, but in the recent years sizeable investments have been made and many more such investments are on the pipeline. It is not known how safe such infrastructures are from mega earthquakes in waiting. Oil refineries and pipelines are another critical infrastructure which are exposed to earthquakes and these must be retrofitted adequately as bursting of oil pipelines may cause fire would compound the damages due to earthquakes.

Earthquake Risk Scenarios

Disaster management is all about mitigation and preparedness based on worst case scenarios, but there is hardly any exercise for building scenarios of earthquakes in the North Eastern Region. On our request the United States Geological Survey developed a rough scenario based on the parameters of 1950 earthquake by applying the PAGER (Prompt Assessment of Global Earthquakes for Response) tools. The results of the study conducted only last month indicate that a 1950 type of earthquake today would expose 19,000 people to violent shaking, 370,000 to severe shaking and about 14 million to moderate to very strong shaking during such earthquake. Estimated fatalities indicate a “red alert” suggesting very high casualties in such scenario. Late night earthquake when people are in sleep would increase the casualties further.

The 1950 earthquake had killed 1500 people when the total population of the North East was about 10 million and the urban population hardly 2 lakhs. Today the population of the region has multiplied nearly five times to nearly 49 million and the urban population has swelled forty-five times to nearly 9 million. Simple application of arithmetic would suggest a casualty figure that would not be very different from some of the worst earthquakes recorded in recent years elsewhere in the world.

The epicenter of 1950 earthquake was located far away from the habited areas in a remote corner of Arunachal-Tibet border. If similar earthquake occurs in a location nearer the capital cities, like the densely populated city of Guwahati, the casualties could be beyond our imagination. It is necessary that reputed academic and research institutions including the National Institute of

Disaster Management develops such worse case scenarios based on available information to be supplemented by further field studies to identify the critical gaps in earthquake mitigation and preparedness in the region.

Earthquake Risk Management

No doubt a mega earthquake in the North East would completely overwhelm the local and provincial governments and therefore the national government shall have an important role to play for the management of such earthquakes. Unfortunately comprehensive plans for preparedness and response to such situations and the roles and responsibilities of different organizations at all levels are yet not in place.

The Disaster Management Act of 2005 has provided a legal and institutional framework for holistic management of all natural and manmade disasters in the country. While disaster management institutions are in place at the national level these are still in making at State and district levels.

The National Disaster Management Authority has released the National Policy on Disaster Management in November 2009 with a vision to 'build a safe and disaster resilient India by developing a holistic, proactive, multi-disaster oriented and technology driven strategy through a culture of prevention, mitigation, preparedness and response'. Earlier in April 2007 the Authority had issued comprehensive national guidelines for the 'Management of Earthquakes'. These guidelines rest on the following six pillars of seismic safety for improving the effectiveness of earthquake management in India:

1. Earthquake resistant construction of new structures
2. Selective seismic strengthening retrofitting of existing priority and lifeline structures
3. Improvement of compliance regime through appropriate regulation and enforcement
4. Awareness and preparedness of all stakeholders
5. Capacity development (education, training, R&D and documentation)
6. Strengthening emergency response capabilities in earthquake-prone areas.

Based on the National Policy and National Guidelines, the national, state and district level plans have to drafted and further updated on a regular basis. While the National Plans for earthquake mitigation, preparedness and response are still in the making, some of the States and districts have developed disaster management plans but most of these plans are not yet validated and tested. Most of the district plans prepared in the North East do not provide any clue whatsoever on how a big or mega earthquake in the region shall be handled.

Considering the inter dependence of the North Eastern States and districts in a situation of a major disaster the North Eastern Council has formulated a Regional Framework for Disaster Management which inter alia flagged the following issues of earthquake risk management in the region:

a) Compilation of authentic data-base and coordinated R & D Studies under competent supervision and monitoring
b) Microzonation and vulnerability mapping
c) Development of predictive and advance warning capability
d) Mass awareness campaign
e) Capacity building of various Stakeholders on subjects that may include the following:
    - Skilled knowledge on seismic risk, vulnerability and quake-resilient structures
    - Preparedness and response skills relevant to the area/risk/situation
    - Retrofitting of existing buildings/structures (especially of Lifeline structures)
    - Modified Town Planning Regulations and Building Bye Laws and massive training campaigns for all those involved in constructions

Mr. P.P.Shrivastav, Member North Eastern Council has discussed at length the various plans and strategies of the Council for earthquake risk management in the North Eastern region. The Guidelines of the NDMA and the Framework of the NEC are the foundations on which a realistic strategy for earthquake risk management in the North East has to be developed.

Good Practices on Earthquake Risk Management

It may be worthwhile to look into some of the global good practices on earthquake risk management. USA, Japan, New Zealand and more recently Turkey and Gujarat are good examples of successful earthquake risk mitigation programmes that may provide important lessons for designing similar programs in the North East. The 7.9 earthquake in San Francisco in 1906 had killed more than 3000 people and rendered 80 per cent population of the city homeless. The reconstruction of the city provided opportunities to develop legal and institutional systems for earthquake resistant designs of all new buildings and infrastructure and retrofitting of existing structures. A special State Bureau was created to control the design and construction of all buildings and infrastructure. The State of California, the Federal Government, including the military, the private industry and the community joined hands to assess the existing risks to specific sectors of the economy and to reduce that risk through earthquake strengthening programmes. The subsequent earthquakes of Long Beach in 1933, San Fernando in 1971, Loma Prieta in 1989 and Northridge in 1994 provided opportunities for testing the systems and further improving them with better standards of earthquake risk mitigation.

The 8.3 Great Kanto Earthquake of Japan in 1923 killed 142,000 people and devastated the cities of Tokyo and Yakohama. Over the years Japanese have developed robust techno-legal and techno-financial regimes that have helped to ensure that all new constructions take place as per earthquake resistant design and technology and all existing structures are retrofitted to withstand the shocks of earthquakes. Despite these regulations the 1995 Great Hanshin Earthquake in Kobe killed 6434 people and exposed many gaps in the system which were further strengthened by more stringent regulations and enforcement.

Following two destructive earthquakes near Istanbul in 1999, the government of Turkey, with funding, guidance, and direct assistance from the World Bank, initiated in 2006 a major earthquake risk management program – the Istanbul Seismic Mitigation and Emergency Preparedness Program (ISMEP). The program is multi-faceted, but its primary component was the strengthening and reconstruction of priority public buildings. The government set up a small unit, the Istanbul Project Coordination Unit (IPCU) to manage the program, with assistance from experienced international experts.

Back home in Gujarat, the 2001 earthquake in Bhuj that killed more than 13,000 people directly led to the creation of Gujarat State Disaster Management Authority which implemented a 1.9 billion dollar World Bank assisted earthquake reconstruction project. The project provided opportunities for comprehensive earthquake risk assessment, enforcement of earthquake resistant building designs, retrofitting of existing building and capacity development of engineers, architects and masons throughout the state of Gujarat.

The North Eastern region must learn from all these well documented good practices and act now without waiting for mega disasters to strike them.

Strategic Issues

This workshop has been designed to bring together experts, policy makers and administrators to discuss the strategic issues of earthquake risk management in the region and to develop a broad road map for implementation through a participatory process involving all concerned agencies of the Government of India, the State Governments, the local authorities and other stakeholders.

The important strategic issues for consideration in the workshop are:

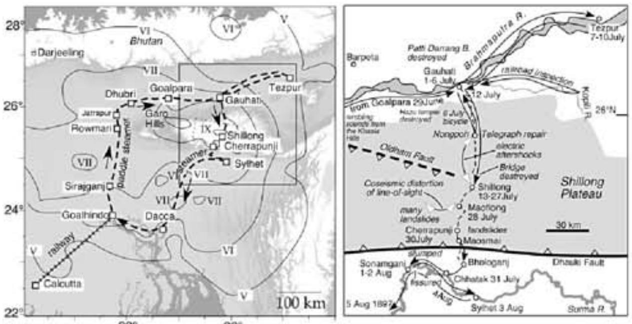
- What are the current gaps in our understanding of the hazards of earthquake in the North Eastern Region and what specific and time bound agenda for action should be taken to address these gaps? The agencies responsible for attending to the specific sub activities under each of the agenda should also be identified.
- What are the types and nature of vulnerabilities of the existing public and private buildings and infrastructure in the region and what needs to be done to strengthen them? How shall these buildings and infrastructures be assessed from earthquake safety points of view? What methodology shall be followed for such assessment and what should be the timeline for the same?
- What are the priority buildings and infrastructure that should be taken up seismic strengthening and retrofitting and how shall funds be arranged for the same?

- Are the BIS Codes adequate to ensure the safety of buildings? Do these require any revisions in the specific contexts of the North East?
- How shall the engineers, architects and masons in the North East be trained in earthquake resistant building designs and technology? What are the total numbers and who will train them?
- Have the BIS Codes been adopted in the Building Bye Laws of the urban and rural local bodies in the region? What prevents the adoption of these codes formulated nearly a decade back?
- What are the factors that constrain the enforcement of Building Codes in areas where such Codes are part of Building Bye Laws? What measures need to be taken to ensure that there is zero tolerance of non compliance to such codes?
- What is the worst case scenario of earthquakes in the region, districts and towns? Is there any plan to respond to such situations?
- What next?

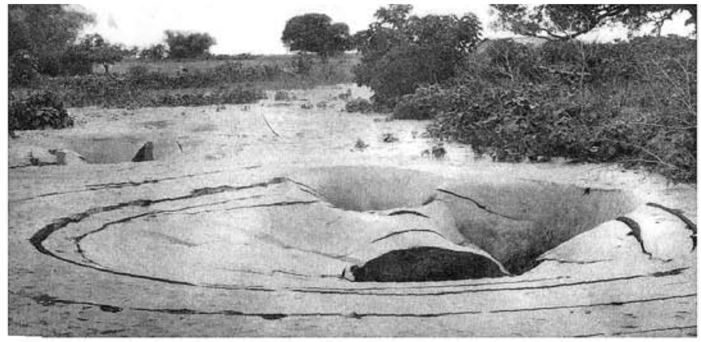
PHOTO FEATURES

FROM THE ARCHIVES

IMAGES OF THE GREAT ASSAM EARTHQUAKES 1897 AND 1950



LaTouche's epicentral route superimposed on an isoseismal map of the 1897 earthquake prepared by Ambraseys and Bilham in 2003.



A sand vent near Rowmari photographed by LaTouche.

The bridge across the almost empty Ward Lake in Shillong after the 1897 earthquake. The dam holding the waters of the artificial lake burst in the earthquake, killing several people.

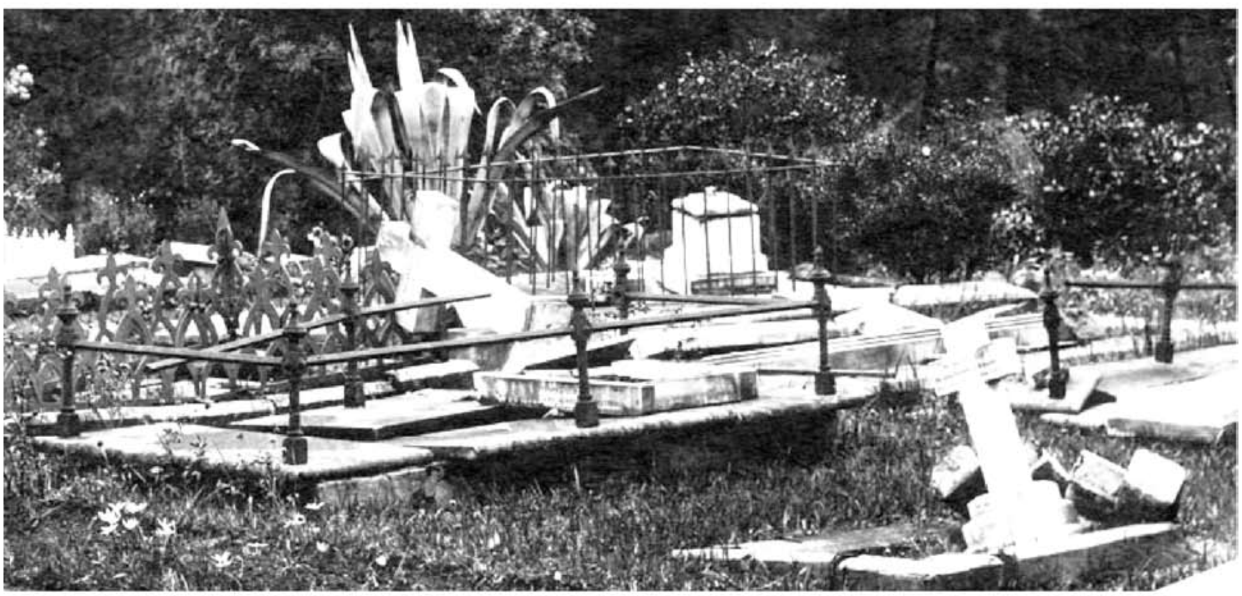
Cracks in upper Assam Trunk Road

A fissure at Rowmari photographed by LaTouche of the Geological Survey of India who was deputed to do the study.. A row of eight still-standing thatched village huts can be seen behind the figures. In his report LaTouche notes: "At Rowmari, besides the fissures parallel to the bank of the river, which here runs nearly NE and SW, a large fissure runs to the SE at right-angles to the river bank for a distance at least 500 yards when it gets lost in a jheel. It is said to run a distance of 9 miles from the river, and very likely extends further than I traced it. This fissure runs along the edge of a tract of ground, on which the village stands, rather higher than the level of the river bank, probably marking the line of an old river channel. Sand and mud have been ejected from the fissure to a depth of at least four feet. Other fissures branch off from this through the higher ground to the north, one of them passing through the huts of the villages."

Collapsed bridge outside of Shillong thrown from its abutments by the earthquake. Mrs. Sweet and Mr Monaghan had just ridden across it. In his official report LaTouche states: "The large bridge on the Gauhati road about 1.5 miles from Shillong, over the Umkra River, has suffered severely. The abutment on the SE side fell entirely carrying the girders with it. The two piers and the abutment on the northwest side which are of more recent construction, remained standing though somewhat cracked.

FROM THE ARCHIVES
IMAGES OF THE GREAT ASSAM EARTHQUAKES 1897 AND 1950

A collapsed portico in Calcutta due to Shillong Earthquake of 1897. The picture appeared in an article written by LaTouche ten days after the earthquake, and published 22 July 1897. In his article LaTouche emphasizes shoddy construction as the chief reason for building collapse in the city.



Gravestones in the cemetery in Shillong were tumbled, shifted and thrown. LaTouche chose simple shapes to document, whose measured shifts in position provided quantitative estimates of acceleration and ground velocity Oldham returned in the dry season after the monsoon and documented further evidence of projected, snapped and displaced monoliths.

The McCabe's bungalow before and after the earthquake.

Flattened buildings, Shillong after 1897 earthquake.

FROM THE ARCHIVES
IMAGES OF THE GREAT ASSAM EARTHQUAKES 1897 AND 1950

All Saint's Church before and after the earthquake

Ruins of Government House Shillong after the earthquake

FROM THE ARCHIVES

IMAGES OF THE GREAT ASSAM EARTHQUAKES 1897 AND 1950

The road from Gahauti to Shillong was fissured during the earthquake, and in some locations landslips had blocked the road and brought down telegraph wires hindering supplies and news to-and-from the epicenter.

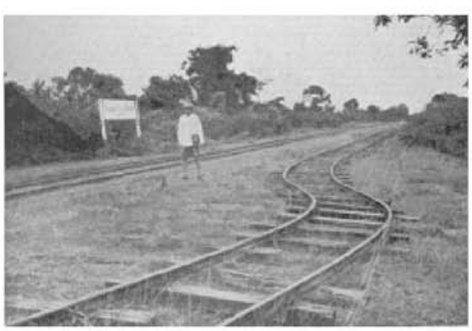
Damaged building in Guwahati after 1950 earthquake

Subsidence of railway embankment replaced by wooden sleepers in Dum Duma

Cracks and subsistence in Upper Assam Trunk Road, Khowang

Majuli - the world's largest river island is gradually eroding to the mighty Brahmaputra. The procession of erosion started with the great earthquake in1950 and continues unabated. Originally with a total area of 1250 sq. km, the island is now left with only 480 sq. km.

In deference to the tragedy, cricket was banned by the Chief Commissioner at Shillong following the earthquake. The restriction was unpopular and the order was rescinded in late July.



Loop formed on railway lines at Dangari

Bridge on Ranganadi North Lakhimpur

Temple at Dibrugarh damaged by the earthquake of 1950

Vulnerable Buildings in Capital Cities of North Eastern Estates

Vulnerable Buildings in Capital Cities of North Eastern Estates

Chandan Ghosh
Professor (Geohazards), NIDM

AGARTALA

Altitude: 1132 meters

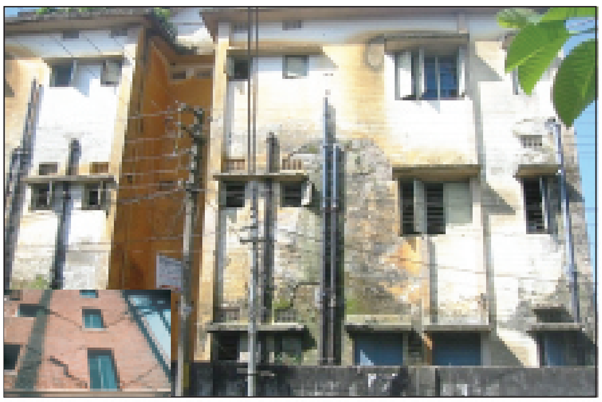
Population: 96,000 approx.

Temperature: Summer Max.29 Min.20 Degree Celsius, Winters Max.21 Min.11 Degree Celsius

Rainfall: 3000 mm

Best Season: October to May.

Clothing: Summer - Cottons, Winter - Woolens

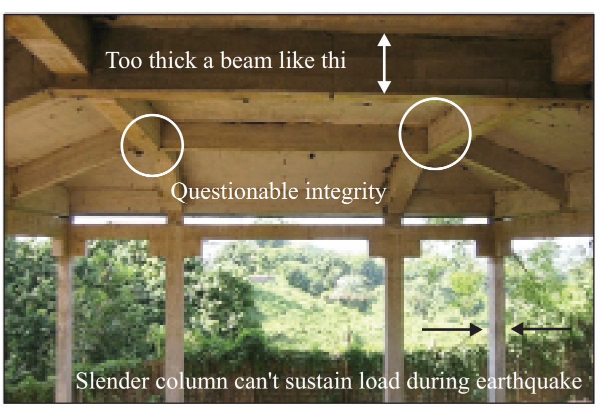


Observation: Appartment buildings made of brick walls and possibly without columns are not to be built in Seismic zone -V in Agartala. Window positions and water tanks are not placed symmetrically

Action: The building needs maintenance or complete demolition. No buildings should be made without beam-column frame.

Observation: This new building with such a front portico may attract earthquake forces for which it is not designed. The supporting beam-column frame without infills may render structural failure due to earthquake.

Action: Remove the portico or fill up the openings with brick walls/cross bracings. Buildings in EQ. prone area should of regular geometry in plan and elevation.



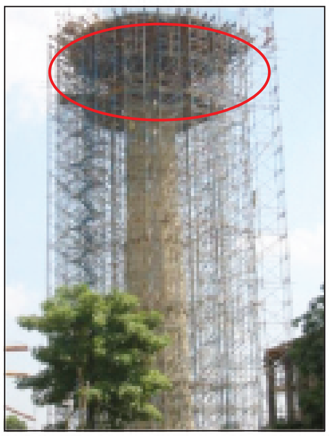
Observation: This portico at the New capital complex is prone to structural collapse. Irregular beams and slender columns are not strong enough to cater earthquake forces. Gaps provided at the interstices of two beams have rendered the column to react as short column, which is dangerous during earthquake vibration. Columns are slenderer than beams, which is against IS code.

Action: Provide cross bracings and fill up the gaps with concrete or bricks

Observation: Emergency section of Agartala Hospital lacks facilties for designated spaces for Ambulence. Openings at varied elevation is prone to damages during earthquake Action: Provide facilties for smooth fuctioning of emergency medical services at the front gate

Observation: Openings given are covering entire length of wall, which according to IS code shall not exceed 50%. Moreover, columns are subjected to behave "short column" mode during earthquake vibration. After 2nd floor, the building has floating walls and columns, which are detrimental to building response during earthquake.

Action: Window openings must be reduced and to reduce short column effect air gap may be provided between column and wall



Observation: Elevated water tanks are the most vulnerable structure in a city because they function as inverted pendulum during earthquake. This water tank at the New Medical college campus , despite taking care of quality design and construction, will be subjected to excessive tilt/settlement due to distant earthquake in the Himalaya.

Action: Empty tank condition vis-a-vis Intermittant water supply may reduce earthquake impact but strenthening of the same may not be feasible.

Observation: Many multistorey frame buildings are being constructed with floating walls. These are made on small projection of the floor slabs, which eventually can not become effective as shear resisting wall

Action: Though shear resistance of walls are not usually accounted in the design of such frame buildings, making floating wall over cantilever projection render the building vulnerable to strong shaking. Therefore, it is essential to check such overhangs in the buidling

Observation: This new assembly complex has been constructed as per standard design practice by a reputed company. Quality control was ensured to the fullest satisfaction of the client. However, this building too is having wide openings to allow bright sunlight. These openings are extended to full width available between columns and they are less than 50% of the wall panel area. But in doing so columns have become shorter, which is not resilient against strong motion. These roofs are prone to damages.

Action: Openings must be regulated as per IS :1893 code

AIZAWL

Altitude: 1132 meters

Population: 96,000 approx.

Temperature: Summer Max.29 Min.20 Degree Celsius, Winters Max.21 Min.11 Degree Celsius

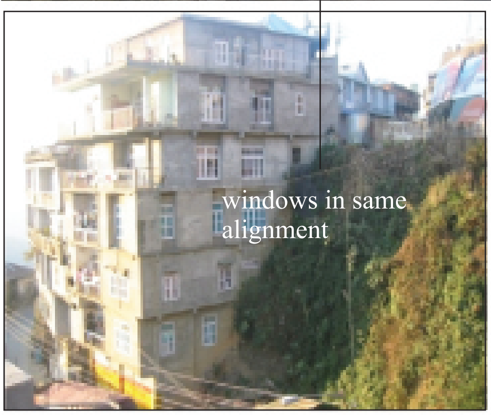
Rainfall: 3000 mm

Best Season: October to May.

Clothing: Summer - Cottons, Winter - Woolens

Observation: This parking shed near Theological college campus has robust, irregular slender beam supported on thiner column. The shed is made on stiff slope with very poor quality concrete. To facilitate unobstructed parking , one centre column has been avoided, thus rendering the entire shed vulnerable to eathquake induced damages

Action: Immediate demolition is required

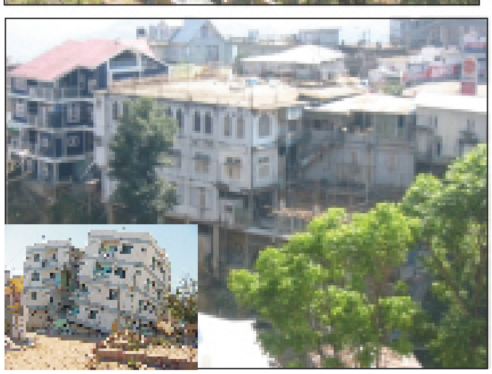


Observation: The building is partly on slope, so the foundation level are of questionable integrity. It is highly irregular in shape and elevation. The load is not unformly distributed. Window openings are not symmetric. Columns are not seen externally, thus it is having floating wall which are dangerous during earthquake

Action: Demolition floating walls may reduce damage potential, however, such buildings are not economically feasible to retrofit

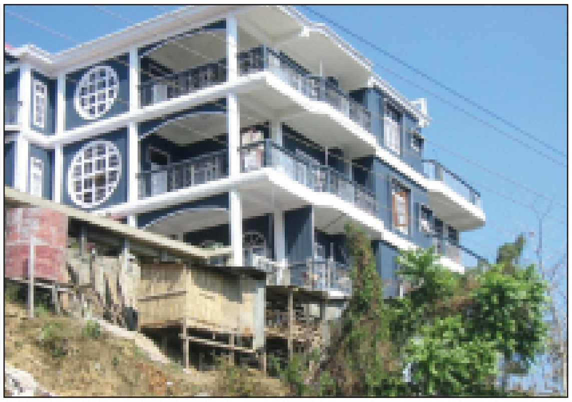
Observation: Such buildings on steep slope supported by open beam-column frame are extremely vulnerable to earthquakes. Building Foundation at such steep slope are of questionable integrity. These buildings are problem creating even during rains.

Action: By filling the opening with bricks wall may ensure structural stability to some extent but increased dead load may pose trouble to foundation stability. Thus such type of buildings have to summarily be demolished .



Observation: Buildings are so much congested in the unmanageable slopes that their response to earthquakes are bound to be very feeble. There is no regularity in plan, elevation and foundation type. Columns are less than 300mm thick. Open frames render the building to fail by soft storey failure

Action: Nothing is possible except demolition and reconstruction



Observation: These buildings with almost 100% wall panel opening, open veranda, extended chajja, irregular plan and elevation being founded on steep untreated slope are always vulnerable to earthquake induced damages.

Action: No retrofitting measures are feasible economically.

Observation: Getting prepared to cast the slab after beam was constructed long time ago - is definitely unique (local) construction methodology that not prescribed in IS codes. Where is the definition of monolithic construction? Not a single stirrup was found with hook at 135 deg.

Action: The fate of these type of buildings lies with the fateful earthquakes as nothing can be prescribed for saving such kind building from collapse.

Observation: Floating walls on extended slab from 1st floor onwards - these buildings can be saved from earthquake induced damages. The ground floor is not having any partition walls - may be for indefinite period. The construction quality is very poor.

Action: The fate of these type of buildings lies with the fateful earthquakes as nothing can be prescribed for saving such kind buildings from collapse.

Observation: This building is having robust frame structure but opening are wide and short column affect is expected during earthquakes.

Action: The openings in the wall must be regulated as per IS code. In order to avoid short column affect an air gap may be provided at the wall collumn junction.

GUWAHATI

Altitude: 55 meters
Population: 500,000 approx.
Monsoon Months: May to September
Best Season: October to March.
Clothing: Summer - Cottons, Winter - Light Woollens

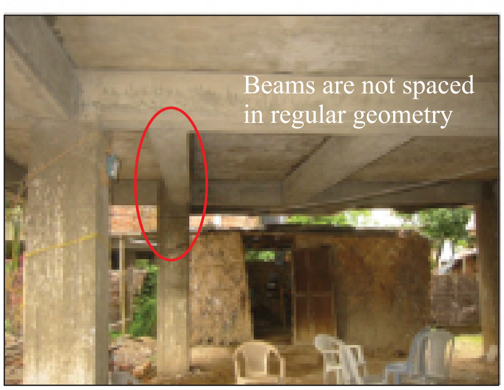
Observation: A typical soft storey syndrome is seen in the 10+ storey apartment building. Such buildings are of immense vulnerability during earthquake. Distant earthquakes, which generates surfaces waves at distance beyond 100 km from epicentre, destroy such multistorey buildings

Action: As disaster implications of such a roubust building are manifold, immediate measures in the form of Shear bracing, viscous dampimg devices, filling of the opening, etc . must be done with priority.

Good example: Cross bracings in the SBI apartment building along Guwahati-shillong road have been provided without compromising with parking facility

Observation: Such building at the congested business places in the Guwahati city portends to many secondary disasters. The contruction quality are questionable. The transmission tower dotting such poor structure renders serious repercussion after earthquake.

Action: The isolated multistoreys must be demolished as soon as possible



Observation: This 5 storey building has robust beam and column but their orientations are awefully unsymmetrical. Earthquake forces find its easy target to the irregular beam - column junction. Such buildings may not collapse suddenly but are vulnerable to sever damages.

Action: Nothing can be done except waiting for the earthquake. Soft storey must be avoided.

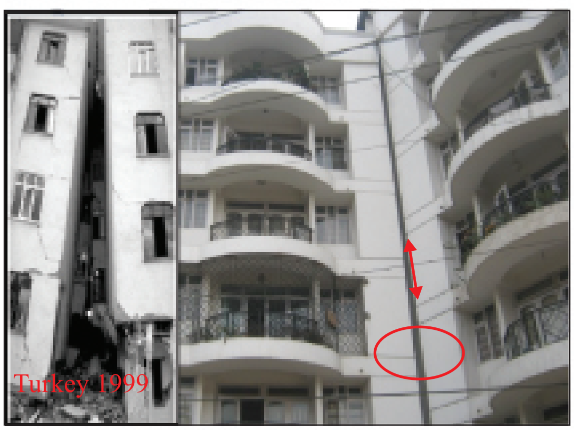
Observation: This building has beam and column but their orientations are unsymmetrical. Earthquake forces find its easy target to the irregular beam - column junction. Such buildings may not collapse suddenly but are vulnerable to sever damages.

Action: Nothing can be done except waiting for the earthquake. Soft storey must be avoided.

Observation: This building at the AASC campus Earthquake forces find its easy target to the irregular beam - column junction. Such buildings may not collapse suddenly but are vulnerable to sever damages.

Action: Nothing can be done except waiting for the earthquake. Soft storey must be avoided.

(inset - short col. failure)



Observation: This apartment building has been showing visible settlement and widening of gap. The esthetic show of the building is not condusive to earthquake resilience

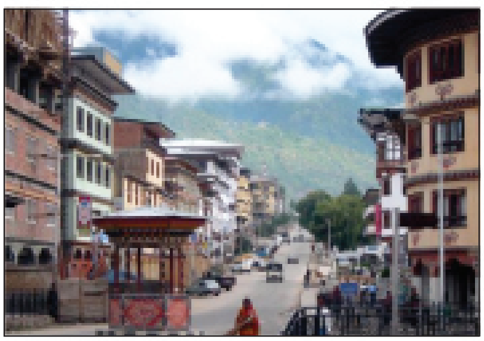
Action: such buildings can't be strengthened by economically sustainable means, however, structural integrity appears to sound good. Settlement of foundation may aggravate further.

Observation: This building has basement with opening for ventilation . The column is restrained by wall, resulting into short column effect. Such buildings are vulnerable to earthquake.

Action: short openings must be closed to avoid stress concentration and damages as shown below

ITANAGAR

Altitude: 750 meters
Population: 150,000 approx.
Temperature: Summer Max.36 Min.23 Degree Celsius, Winters Max.28 Min.12 Degree Celsius
Rainfall: 2660 mm
Best Season: October to March.
Clothing: Summer - Cottons, Winter - Woollens



Observations: Multistorey and multi tired buildings are having extensive openings for daylighting. Many are having overhanging at the top that render vulnerability. Storey height , window openings are not uniform all storeys.

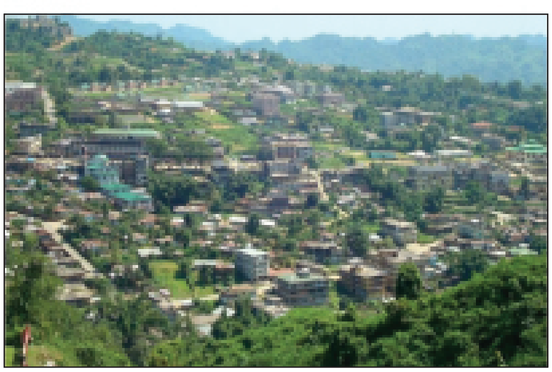
Earthquake resiliency performance of the buildings are questionable as quality construction and monitoring of construction process are not routinely done in majoriity of the cases.

Repairing and strengthening measures can be decided after proper survey of the building stock. Howver, in majority of the cases evaluation of such measure are costly affair

Action: RVS is essential for the building stock.

Observation: Vehicle shed standing on slender column as shown are vulnerable to earthquake shaking

Action: Bracings may be provided for strengthening of the shed



Observation: Buildings of varied height and shape standing on the gentle slope sre subjected to earthquake induced landslides. Rescue operations are not easy to do.

Action: Proper drainage of rainwater must be maintained . Slopes are to be treated well against landslides.

KOHIMA (NAGALAND)

Observation: Two buildings having different elevations at the ground level and found 2nd floor at same level but with floating wall at the 1st floor at different allignment. Windows are not in proper shape, size and allignment. Overhangs at the 2nd floor with floating parapet contributes to poor performance during earthquake.

Action: Buildings of such nature can't be retrofitted due to poor quality worksmanship. Only option remains to wait and see the impact of earthquake

Observation: This building has large areal extent with openings at various level and sizes. Shape is not regular. Floating walls are rampant and chajjas are not in proper orientation. New constructions at the upper floors seem to have overlooked appropriate modification in the foundation

Action: such construction at the hill area must be checked with caution, else they have potential to create seccondary devastation to adjacent establishments

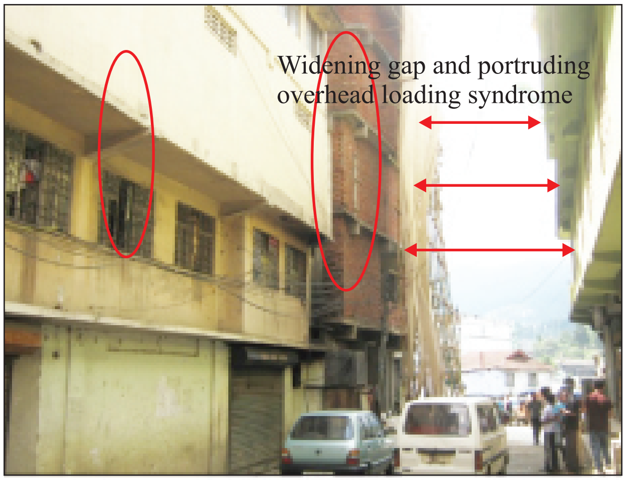
Observation: Row of shops supported by these columns depicts very poor resistance to earthquakes. Columns are showing reibars and quality of construction is very poor. Such type of structures are not at all desired in earthquake prone area

Action: Columns may be strengthened by jacketing but load bearing capacity can't be ensured. Demolition is the only option

Observation: Such type of HYBRID structures, i.e., combination of RC -at the ground and Ektra type at the 1st floor, though elegant and exclsively found in the region, are not earthquake resistant. Because EQ. resistant structures must be regular in shape and elevation. Stiffness at subsequent floors can't vary abruptly. Moreover it has floating walls

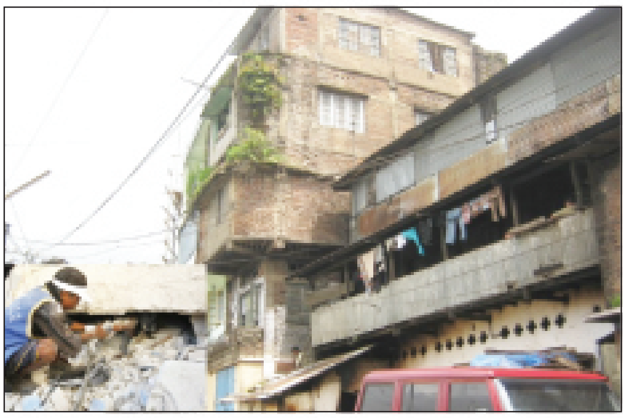
Action: As upper floor is lighter than the ground, it may not face sudden collapse but damage will be substantial due to changes in stiffness at ist floor

KOHIMA (NAGALAND)



Observation: A good number of buildings are spreading in steps as they go up in no. of storeys. It may be assumed that walls in the stepped out floor are well supported by the underlying wall, which is not at all true. EQ. induced vibration effect on such inverted pendulum type buildings will be severe.

Action: Such construction practices must be stopped and regulated by qualified professionals.



Observation: Buildings are very poorly constructed. EQ. impacts will be collossal. (inset pho to shows devastation at Haity EQ. 2010)

Action: Retrofitting measures will be totally misfit for such weak buildings.

Observation: Buildings are of questionable integrity from EQ. resistance perspectives. Floating walls on extended slab makes building more vulnerable.

Action: Such construction practices must be stopped.

Observation: Constructions in phases are very common many cities in NE. But casting beam partially and together with slab in later date, have no relavance to any national standards or guidelines. As per IS code, beam, column and RC slab must be cast monolithically.

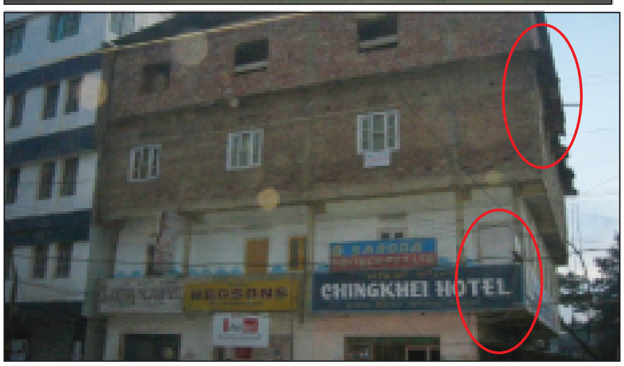
Action: Such construction practices must be stopped.

IMPHAL (MANIPUR)

Area : 29.57 sq. km.
Attractions : Khwairamband bazar, Keibul Lamjao National Park.
Altitude : 790 meters above sea level.
Temperature : max. 32°C min 0° C.
Rainfall : 1980.8 mm (May to October).
Best time to visit : October to February.

Observation: This building is having poorly built open frames and supporting a communication tower. Stability of such structures can not ensured even during seasonal variation

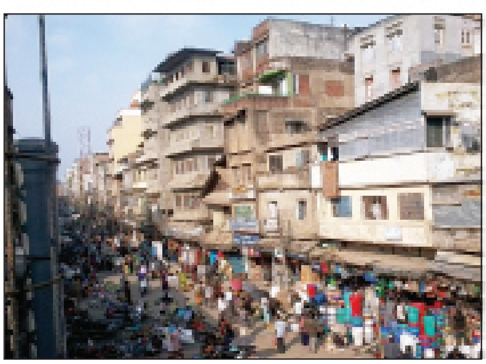
Action: It requires strict regulation of such construction dotting with communication tower.



Observation: Buildings of such types are plenty in the whole of Imphal town. These are of extremely poor construction with all deffects, such as floating wall on gradually extended floor, poor mortar and brick work, feeble load bearing column, irregular geometry in both plan and elevation.

Action: Nothing can be done to strengthen such structures. Economy of Retrofitting would be a big burden. Diagnosis of structural and nonstructural defects would extremely difficult yet challenging. Therefore, these are to be categorised as high risk building with possible economically feasible balm except demolition (Inset Haiti EQ. 2010)

Construction quality as seen at the important market complex in Imphal city , or for that matter in majority of the cases in the entire India, depicts how with such manual handling of building materials defies our structural designer's best possible earhquake resistant expertises (using sophisticated SAP, PERFORCE, ANSYS, etc.).



Observation: Buildings of nondescript structural integrity are juxtaposed with each other in varible floor heights, lateral dimensions and geometry. During earthquake each building unit will be subjected to vibration that may give in to punding effect (see inset photo from Mexico, 1985)

Action: Even scaling vulnerability of such poorly constructed building stock will be implausible exrcise. No technique, such as NDT - Rebound Hammer, GPR, etc. would be justified to check multi-oraganological construction deffects

SHILONG (MEGHALAYA)

Observation: This new building on open frame (tilt) and with floating walls calls for dangerous consequence during earthquake. Openings seen at two sides of floating walls are not at same level. Irregular combination of columns and beams are not desired in earthquake resistant construction.

Action: this buildings needs immediate closure of all open spaces by brick wall or X-bracings. No amount of reibars in the load bearing columns are adequate enough to sustain earthquake forces

Observation: This new building, though showing lintel beams - which otherwise almost absent in majority of modern building stocks, is being led to unsafe mode as floating walls are the verse of construction. Size of corner column is less than 30cm thick and inner column, as seen here, is even thinner. Such variation in load bearing columns must be avoided

Action: Regulation of such new construction from possible EQ. effects must be done hence forth else these type of ill-configured buildings are leading to poor performance for entire life period of the same.

Observation: Poor quality constructions that now being seen (before plastering) in the load bearing members; will be difficult to trace later even if City Govt. decides mass scale RVS and detail vulnerabity check.

Action: Such constructions need careful supervision and quality checking before completion. Else they remain vulnerable and dangerous accredition to the society

Observation: These type of buildings, after learning the lesson from 1897 earthquake, has shown credible performance and integrity in the entire NE region. But there is no such large scale tests performed on shaking table. Such buildings are light and rigidly connected at the joints.

Action: Irregurality in plan and elevation must be avoided. These days Reinforced conc. structures are marriaged with such type of buildings, which is to be stopped and checked for structural integrity

SHILONG (MEGHALAYA)

Observation: Construction activities are taking place without any regulation and check. Many buildings remain unfinished with open soft storeys. windows/Openings are kept at desired will that have no semblance from EQ. impact. (inset shows how open basement suffered damages)

Action: Construction regulation and quality monitoring must be precisedly enforced

Observation: Buildings on the crest of cut slopes are nobody's concern till problems faced. If not controlled while planning, settlement of foundation or drainage related problems may arise. In many places cut slopes are left exposed in the rains and thus causing seepages related problems. EQ. effects will be aggravated in addition to landslides.

Action: Construction regulation hill areas must be enforced. Drainage must be regulated at the cut slopes

Observation: This building at the NEC campus, Shillong demonstrates feats of earthquake engineering design principles. It is considered finest example of earthquake resistant construction. However, it's resilience to actual earthquake shock of M8+ can not be ascertained by any performance standards available in India.

Action: Making EQ. resistant buildings in hilly areas requires site specific data, which at this moment is not available for Shillong city. Hazards mapping standards must be upgraded to take care of vulnerability of buildings resting on steep slopes.

GANGTOK (SIKKIM)

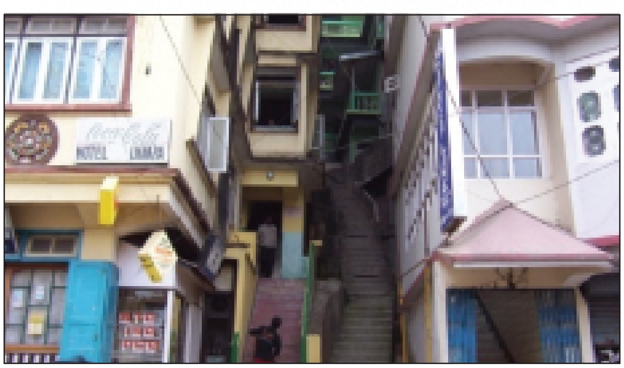
Area : 7290sq km
Population : 420, 000
Capital : Gangtok
Chief Language : Nepali
Best Time to Visit : March to August

Observation: Eight storey building with isolated mumpty standing at the sloped surface brings testimony to the vulnerability of many such buildings in the state capital of Sikkim (Below shows the soft mid storey failure observed in Bhuj 2001)

Observation: Buildings in Gangtok are highly vulnerable mainly due to excessive height and insufficient breathing spaces. Earthquake resistant construction measures not followed routinely. Though load bearing columns and beams are provided in most of the constructions, they donot feasibly meet criteria for earthquake forces by taking into account of site response factor. Simple consideration of zone factor (as per IS: 1893) does not suffice for buildings in hilly terrain.

Observation: This multistorey building has well defined beams and columns but brick walls on extended floor and load bearing column not passing at the corner, imparts high degree of vulnerability.

Open soft storey at the bottom, if not yet mended by appropriate measures, makes the building summarily vulnerable.



Observation: There is hardly any spaces in between buildings. EQ. may lead to severe damages to nonstructural components of such buildings.The long narrow staircase is not appropriate to cater rescue operation.

Action: No strengthening measures will be able to rectify such building stocks from EQ. effects. However, with the help of regular mockdrill and DM planning in place, expected loss to human life may be checked to some extent.

GANGTOK (SIKKIM)

Observation: Gangtok has lots of multistorey buildings that needs disaster auditing. Lanes are narrow with 8+ storey building units standing side by side. (inset photo shows response to EQ.)

Microzonation study on Gangtok city, mostly done so far to identify hazards (from science of seismology) perspectives, has not yet brought out requisite site response factor. IS:1893 does not address this issue either. Risk mapping based on appropriate vulnerabily scoring of each building unit has been done so far.

Therefore, with no specific building bye-law in place and in-force, fragile implemenation drives by the municipal authority renders builders, contractors and owners to adopt measures deem to their understanding and experience.

Constructions as such are not so poor in Gangtok. But making multistorey buildings on open foundations at the steep slopes and with floating walls, soft storeys together make them extremely vulnerable.

Action: Construction quality needs proper checking by qualified structural engineer.

Mere, usage of destructive and nondestructive tools; along with sporadic soil and geolological investigations may be construed to decide upon some causative factors of Building Physiology. Mapping of buildings must be done based on sound engineering judgements and experimental performance monitoring.

Buildings bye-laws are somewhat ideal under normal situation. Rules from these guidelines can't be fit well into the majority of the building stock in Gangtok. Therefore, DM planning is a must and they should be implemented as per situational demands.

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