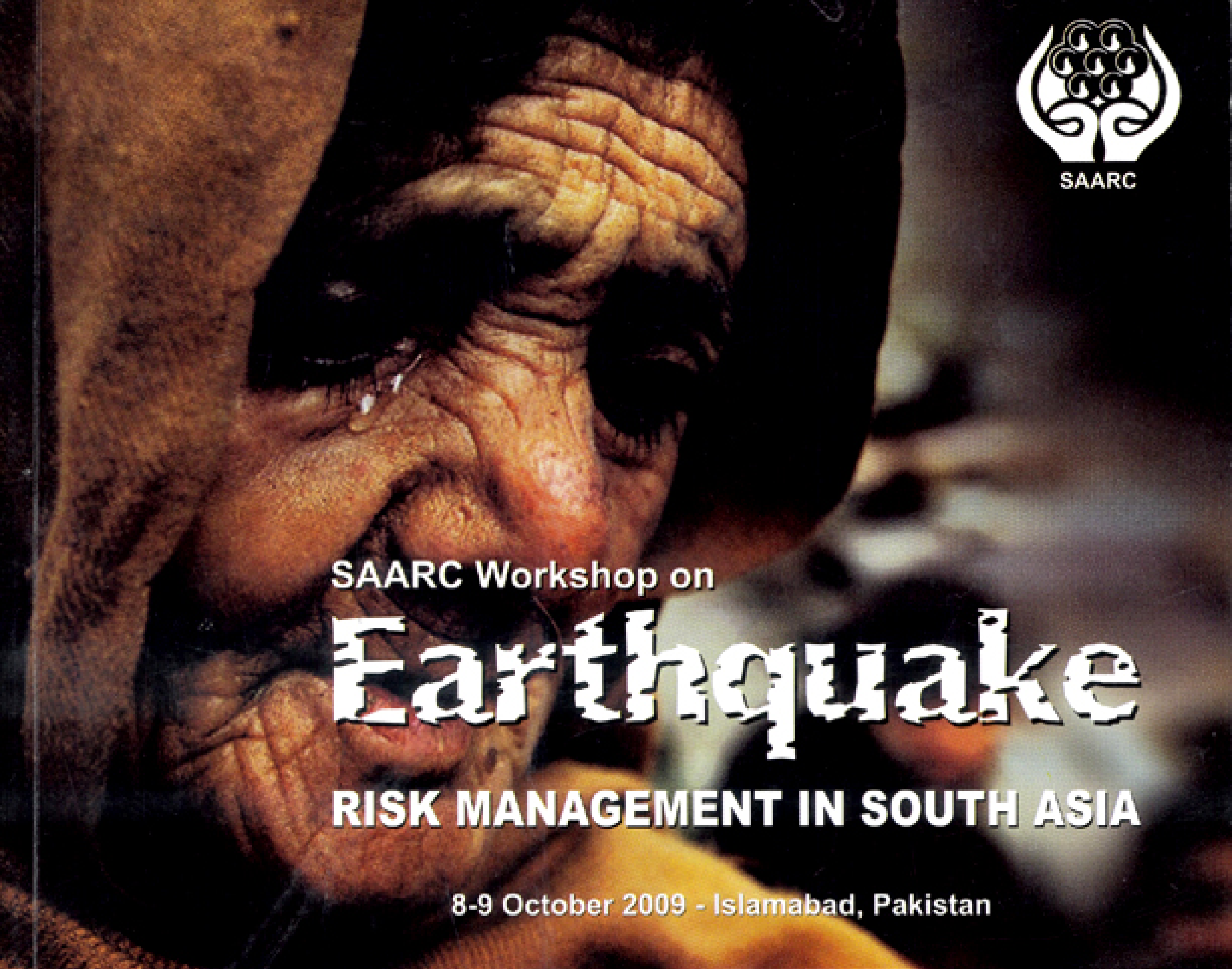


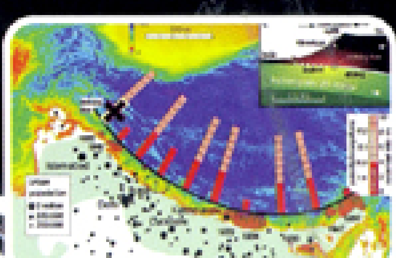
SAARC

SAARC Workshop on

Earthquake

RISK MANAGEMENT IN SOUTH ASIA

8-9 October 2009 - Islamabad, Pakistan



Organized by

SAARC Disaster Management Centre, New Delhi

In collaboration with

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Contents

Background Paper

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Introduction

1.1 South Asia is one of the most earthquake prone regions in the world. Six out of the eight countries of South Asia, namely Afghanistan, Pakistan, India, Nepal, Bhutan and Bangladesh are located within most seismically active Himalayan - Hindukush belt which has seen some of the worst earthquakes recorded in human history. Parts of Indian peninsula as also the island territory of Andaman & Nicobar have major seismic fault lines that have ruptured time and again.The remaining two countries, Sri Lanka and Maldives are vulnerable to tsunamigenic earthquake in the Indian Ocean. A large part of the coastal areas of Bangladesh, India and Pakistan are similarly vulnerable to underwater earthquakes originating in Indian Ocean and Arabian Sea.

1.2 Earthquakes have caused heavy damages in terms of deaths, injuries, destruction of habitat and disruption of economic activity that have left scars on a large section of population in wide areas. Realising the potentially catastrophic consequences of largely unpredictable earthquakes, particularly in growing urban areas in different seismic zones of South Asia, it has become imperative that countries of the region pull their resources, expertise and strengths and share their experiences with each other in assessing the risk of earthquakes at regional and local levels, mitigate the risks through a combination of structural and non-structural measures, respond to the earthquake events by rapid response and relief to the victims and reconstruct the damaged houses, infrastructure and livelihood to restore normal life and economy in the affected areas. Such regional cooperation is envisaged under the SAARC Comprehensive Framework of Disaster Management adopted by the Member States. In order to assess the strength and weakness of current initiatives for earthquake risk assessment, mitigation, response and recovery in the region, a SAARC Workshop on Earthquake Risk Management has been organized by the SAARC Disaster Management Centre, New Delhi in collaboration with the National Disaster Management Authority of Pakistan in Islamabad on 8-9 October 2009. The Workshop would develop a Roadmap for Regional Cooperation for a short, medium and long term basis for earthquake risk management in the region.

Pattern of Earthquakes in South Asia

2.1 Till recently the seismic networks in South Asia remained rather sparse and historical data on earthquake over centuries are also not adequate. Based on the analysis and inference from available data the frequency and magnitude of earthquakes in South Asia can be presented in the following table:

Table 1: Frequency and Magnitude of Earthquakes in South Asia

Descriptor	Magnitude	Frequency
Great	8 +	1 in 25 years
Major	7 - 7.9	1 in 16 years
Strong	6 - 6.9	1 in 4 years
Moderate	5 - 5.9	35 every year
Light	4 - 4.9	1550 every year (estimated)
Minor	3 - 3.9	5500 every year (estimated)
Very Minor	2 - 2.9	100,000 every year (estimated)

2.2 In terms of fatalities only earthquakes of magnitude 6 and above are known to have caused damages to life and property, although there are evidences that earthquakes of lesser magnitudes did cause cracks in structures and trigger landslides. The cumulative effect of such damages could be fatal, but very few empirical studies on such damages are available.

2.3 The ten strongest earthquakes in terms of magnitude with its epicenter in South Asia or its vicinity during the past 100 years were:

Table 2: Ten Strongest Earthquakes of South Asia since 1900

	Date	Mw	Latitude	Longitude	Location
1	26 December 2004	9.1	03.29	95.98	Sumatra-Andaman arc
2	15 August 1950	8.6	28.38	96.76	Chayu -Upper Assam
3	15 January 1934	8.1	27.55	87.09	Nepal-Bihar border
4	27 November 1945	8.0	25.15	63.48	Makran Coast, Pakistan
5	30 May 1935	7.8	28.87	66.40	Quetta, Balochistan
6	4 April 1905	7.8	33.00	76.00	Kangra, Himachal Pradesh
7	26 June 1941	7.7	12.40	92.50	Middle Andaman Island
8	26 January 2001	7.7	23.44	70.31	Bhuj, Gujarat
9	8 October 2005	7.6	34.43	73.53	Kashmir-Kohistan
10	29 February 1944	7.4	00.30	75.30	Near Maldive Islands

2.4 In terms of fatalities the ten strongest earthquakes during the past 100 years were:

Table 3: Ten Most Fatal Earthquakes of South Asia

Year	Location	Magnitude	Deaths in South Asia
2004	Sumatra	9.1	55,000+
2005	Kashmir	7.6	75,900
2001	Bhuj	7.7	13,845
1935	Quetta	7.3	35,000
1905	Kangra	7.8	28,000
1934	Nepal-Bihar	8.1	10,653
1993	Latur	6.4	10,000
1974	Northern Pakistan	6.2	5,300
1998	Afghanistan	6.6	4,000
1998	Afghanistan	6.1	2,323

It is clear that in the recent years earthquakes are becoming more fatal and there are indications that these would be even more fatal in the years ahead due to the increasing exposure more vulnerable population and assets to the risks of earthquakes. So far major catastrophic earthquakes of South Asia have mostly occurred in low population density rural areas. Impacts of such earthquakes nearer the urban centres shall be far more devastating for which the countries of the region are not at all prepared. It is therefore extremely important to assess the risks of earthquake in a comprehensive manner so that appropriate measures can be taken to reduce these risks.

Earthquake Risk Assessment of South Asia

3.1 Earthquake risk assessment involves three aspects: seismic hazard assessment, assessment of building typology and overall exposure of population and assets in hazard prone areas. Seismic Hazard Assessment (SHA) is primarily based on seismotectonics, past earthquake events and damage pattern. It refers to the likelihood and effects of future earthquakes in a region, therefore, can be considered as a measure of long term earthquake prediction.

Seismotectonics of the region

3.2 The world's youngest mountain belt, the Himalaya and Hindukush, envelope South Asia all along its northern fringe, from Afghanistan in the west to Bangladesh in the east. The Himalaya is still evolving due to northward push of the Indian Plate towards the Eurasian plate. As a result Himalaya has emerged as the largest active continent-continent collision zone on earth causing numerous major and great earthquakes. The same process the Indian Plate has collided with the Burmese Micro-plate, resulting in deadly earthquakes in the Andaman and Nicobar Islands. Likewise the northward convergence of the Indian plate against the Eurasian plate has caused seismicity of central and eastern.

3.3 The Indus suture zone marks the beginning of the subduction between Indian sub-continent and Eurasia in early tertiary times. This zone is marked by relict oceanic crust (ophiolite) that separated two continents. With time, the collision boundary shifted southward, and the northern edge of the Indian plate was thrust back onto itself, first along the Main Central Thrust (MCT) and later along the Main Boundary Thrust (MBT). Presently the main tectonic displacement zone lies along the Himalayan Frontal Fault System, which comprises Himalayan Frontal thrust at the edge of the Indo-Gangetic plain, and several anticlines and synclines to the north. spatial distribution of earthquakes in this region is clustered around the surface traces of the main tectonic discontinuities such as MCT, MBT and HFT in the Himalayan range. At the outer fringe, three great earthquakes (M=8) struck the foot hills of the Himalaya in 1905, 1934 and 1950. These are the largest earthquakes that occurred on continental thrust faults and are comparable in scale to the great earthquakes of subduction zones.

3.4 Sometimes earthquakes of different magnitudes also occur within the Indian Plate in the peninsula and in adjoining parts of the Arabian Sea or the Bay of Bengal. These are mainly due to localized systems of stress accumulation along mega structures.

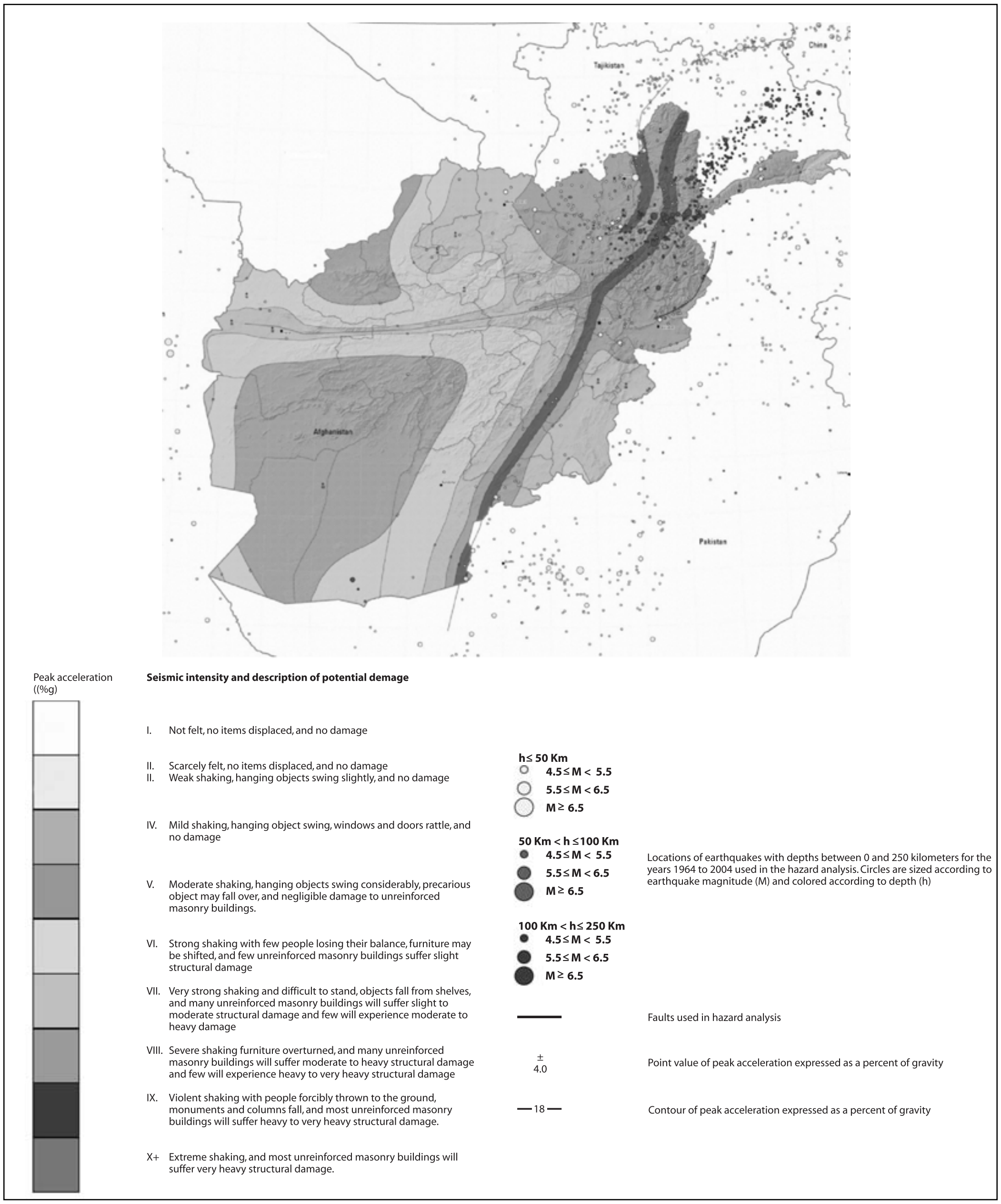
3.5 Seismic risk assessment in the Himalayan region demands comprehensive analysis of information pertaining to seismic hazards across national boundaries, as the countries share common seismotectonic structures. The best way is to use the information available across the neighboring countries in a contiguous manner. This has been attempted under Global Seismic Hazard Assessment Program (GSHAP) for the South Asia and country level maps have been prepared. However, the scale of these maps is no better than the information available at national scale in respective countries. A regional scale seismic hazard map serves limited purpose although it provides very useful broad guidelines on perceived seismic hazard based on seismic and geological data on regional scale. Based on the damage pattern in recent earthquakes, particularly during Bhuj 2001, tsunami of 2004 and Kashmir earthquake of 2005, it is realized that the seismic hazard must be analysed and determined in a much more detailed manner particularly taking into account the local geological and geotechnical and building characteristics and attenuation of the seismic waves. Based on the seismic hazard information available from country sources and from GSHAP programme earthquake risks of each country of South Asia region has been assessed.

Afghanistan

4.1 Afghanistan is located in the tectonically active southern part of the Eurasian plate. The northward motion of the Indian plate and Arabian plate has given rise to mountains and numerous earthquakes in Afghanistan. The distribution of earthquake epicenters in Afghanistan reveals that the northern and eastern parts of the country are more vulnerable compared to the southern Afghanistan that lies on the un-deformed Eurasian plate.

4.2 A preliminary earthquake hazard map prepared by U.S. Agency for International Development (USGS Open-File Report 2007-1137) depicts eastern and northeastern parts of the Afghanistan as very high hazard prone due to presence of faults and past seismic history. Kabul has been estimated to have the highest seismic hazard due its proximity with the active Chaman Fault. The western Afghanistan has low seismic hazard as compared to the east. However, Heart, on the western part of the country, has relatively higher hazard due to its proximity to Hari Rud fault. Kandhar on the eastern part of the country has low seismic hazard as it is located away from the Chaman fault. Earthquakes in the M7.0 range have been experienced in parts of the country. The northeast region, in particular, shows high hazard where most of the shallow as well as deep earthquakes are located at the intersection of Chaman and other fault systems of the region.

Figure 1: Seismic Hazard map of Afghanistan



Bangladesh

5.1 Bangladesh and the northeastern Indian states have long been one of the seismically active regions of the world, and have experienced numerous large earthquakes during the past 200 years. The catastrophic earthquakes of 1762 and 1782 are believed to have been partially responsible for the diversion of the main flow of the old Brahmaputra river from the west to present Jamuna river and main flow of the Arial Khan river to the present Padma channel. Since 1860 over 20 shallow and intermediate earthquake epicenters have been recorded in Bangladesh and the surrounding areas.

5.2 However, absence of strong earthquakes in the recent past have left the present generation unaware of the possibility of a major earthquake. Lack of public awareness along with absence of legal enforcement of building code has resulted in majority of buildings in the urban areas of Bangladesh to be lacking in earthquake resistant design. This is further compounded by poor quality of buildings materials and construction. In case of a major earthquake the densely populated cities of Bangladesh may face a massive disaster. One such potential high risk area is Dhaka, which is one of the fastest growing megacities of South Asia. Seismic hazard assessment studies have confirmed the possibility of intensity VIII shaking in Dhaka city. Soft soils and high ground water table may amplify the earthquake motion and create conditions of lequefaction with very fatal consequences.

5.3 A risk and vulnerability analysis of Dhaka city in the event of an earthquake of an intensity of VIII indicates that about 13.4% of the houses may be seriously damaged and about 64,700 people would be at high risk of death or serious injury in the Dhaka city alone.

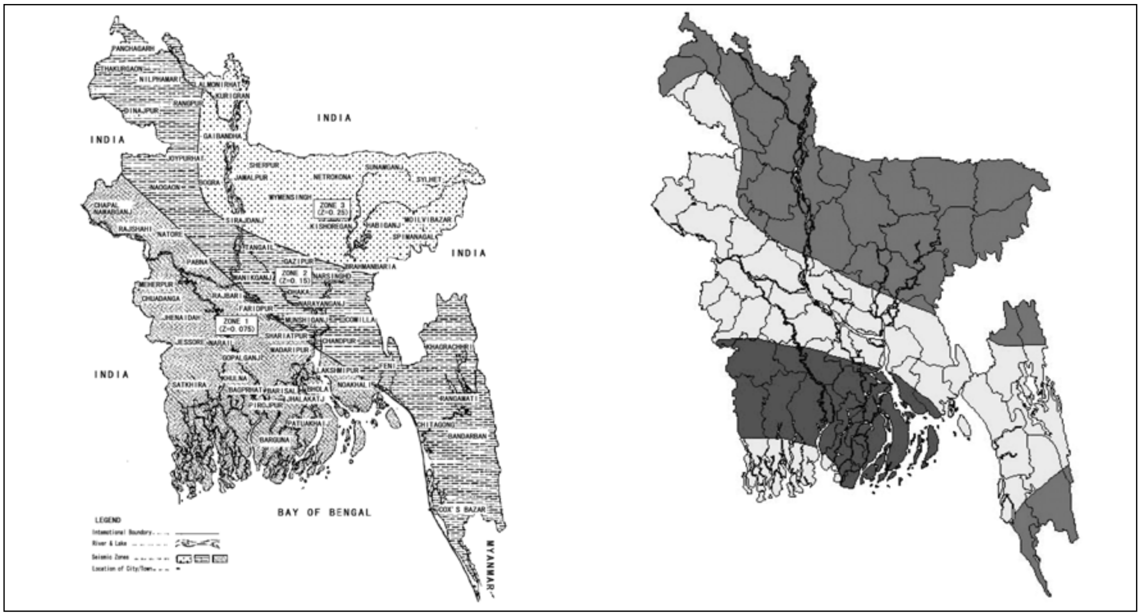
Table 4: Earthquake Risk and Vulnerability Study of Dhaka City

Elements at risk/Thana	Sutrajpur	Lalbagh	West Dhanmondi
URM:RCF buildings	65:35	49:51	32:68
Complete/partial collapse of URM/RCF buildings	5.8%	5.5%	5.3%
Number of people at high risk of death or serious injury	18,600	27,300	18,800
Serious damage to buildings	16.7%	13.5%	10.1%

5.4 The first seismic hazard map of Bangladesh was compiled by the Geological Survey of India in 1935. The meteorological department prepared a hazard map in the sixties that was adopted in 1972. The entire country was divided into four zones: major damage (10% - 20% g), moderate damage (6.7% - 10% g), minor damage (5% - 6.7% g) and negligible damage (< 5% g). The map was further revised in 1979 by the Geological Survey of Bangladesh and an outline of earthquake resistant design was also prepared. This map and the outline formed the basis for designing most of the important structures built during the next 20 years.

5.5 In 1992, the Government appointed a team of consultants to prepare a National Building Code for Bangladesh. As part of this study, a comprehensive review of present data has been undertaken and a revised seismic hazard map has been compiled. The results have been incorporated in the Bangladesh National Building Code. The hazard map retains the major features of the earlier maps and divides the country into three zones. The zone of highest hazard (Zone 3) includes the north and northeastern parts, the zone 2 covers the central part and Zone 1 covers the remaining south- western part of the country.

Figure 2: Seismic Hazard Map of Bangladesh, Old and Updated Version



5.6 According to GSHAP data, Bangladesh lies in a region of low to high seismic hazard that increases in the northern and eastern parts of the country. Historically, earthquakes in the M6.0-7.0 range have been experienced in Chittagong, Dhaka and Sylhet divisions while events in the M5.0-6.0 range have been experienced in Khulna and Rajshahi divisions. However, the hazard maps referred above, do not include the liquefaction effect, which may increase the damage potential in low lying areas with soft sediments and shallow groundwater level.

Bhutan

6.1 The mountainous Himalayan state of Bhutan with a population of 700,000 is situated in one of the seismically most active zones of the world encompassing Lesser and Central Himalayan zone. The adjoining parts of India have been classified as very high hazard that lies in zone – V and IV of the seismic zoning map of India. The major tectonic discontinuities present in the Bhutan Hiamalaya are Main Frontal Thrust, Main Boundary Thrust and Main Central Thrust (Thimphu Thrust). About 46 seismic events have been recorded within the territory of Bhutan during 1928 to 1998. The effect of some of the great earthquakes of the Indian sub-continent like 1897 (Shillong), 1934 (India-Nepal) and 1950 (Assam) have jolted Bhutan as their epicenters lie within a distance of 500 km from Bhutan.

6.2 In recent years, Thimphu, Paro and Phuentsholing have witnessed the effects of three significant earthquakes. The earthquake of 1980 (6.1 on Richter scale), with its epicenter in Sikkim (India), had caused several cracks in buildings in Thimphu, Phuentsholing, Gelephu, Samdrup Jongkhar and Trashigang. There were also reports of some damages caused to houses in the villages. Also, in its aftermath, the Phuentsholing – Thimphu national highway was blocked by landslides caused by the tremor. The earthquakes of 1988 (6.6 on Richter scale) and 2003 (5.5 on Richter scale) with epicenters in the Indo-Nepal border and Bhutan respectively, also caused similar damages to human settlements, institutional buildings (including schools, hospitals, Dzongs etc.) and highways. The twin earthquakes of February, each measuring 5.8 and 5.5 on the Richter scale caused damages to the Dzongs and Lhakhangs in the eastern Dzongkhags of Trashigang, Lhuentse, Pemagatshel and Samdrup Jongkhar. More recently an earthquake of 6.1 on Richter scale with its epicenter 180 km east of Thimphu killed 12 persons.

6.3 Preliminary Seismic Hazard Zonation of Bhutan was carried out by Geological Survey of India. Bhutan was classified into four seismic hazard zones viz. very high, high, moderate and low. According to GSHAP data, Bhutan lies in a region of high to very high seismic hazard that increases towards eastern parts of the country. Historically, earthquakes in the M5.0-6.0 range have been experienced and at least one ~M7.0 event is inferred to have occurred in the 1700's in eastern Bhutan and adjoining parts of India. Therefore, a more systematic and detailed exercise considering the past seismicity, seismotectonics, and active faults in the country and surrounding region, is required for a realistic Seismic Hazard Assessment of the country.

6.4 The most vulnerable region in Bhutan is the Thimphu valley with very high population density and high stage of development. Realising this, Standards and Quality Control Authority, Royal Government of Bhutan, initiated the "Thimphu Valley Earthquake Risk Management Project" (TVERMP) with support from UNDP. The project developed an earthquake risk scenario for the Thimphu valley using RADIUS (Risk Assessment Tool for Diagnosis Urban Areas against Seismic Disasters); conducted vulnerability assessment of 15 critical buildings and produced awareness materials on earthquake resistant construction technology and good practices.

India

7.1 During the last two decades India experienced 6 major earthquakes that have resulted in over 23,000 deaths and caused enormous damage to housing and infrastructure. The Himalayan and sub-Himalayan region is the most vulnerable region. The North-Eastern part of the country continues to experience moderate to large earthquakes at frequent intervals. On an average, the region experiences an earthquake with magnitude greater than 6.0 every year. The western part of the country around Kutch is also highly vulnerable as evidenced by massive destruction during past earthquakes of the region. The Andaman and Nicobar Islands are also situated on an inter-plate boundary and frequently experience damaging earthquakes.

7.2 Geological Survey of India compiled the first national seismic hazard map of India in 1935. The second seismic hazard map was published in 1965 which was based primarily on earthquake epicentral and isoseismal maps in which epicenters of earthquakes with M= 5 were plotted over Modified Mercalli Intensity isoseismals (ranging from V to IX) from some strong earthquakes to determine the seismic zones. Minor modifications were made to account for local effects such as those indicated along the Aravalli axis by the Delhi earthquake.

7.3 As the knowledge domain of seismology expanded, two revisions of the national hazard maps were made in 1966 and 1970, respectively. The revised maps more closely represented known seismotectonic features without sacrificing the information obtained from earthquakes and from theoretical ground motion attenuation relationships. As per the latest Seismic zoning map of India (IS 1893:2002), the Indian landmass has broadly been classified into four distinct seismic zones, viz., Zone-II, III, IV and V, based on their liability to different degree of seismic intensity, as given below:

Zone V: Very High Damage Risk Zone liable to experience seismic intensity IX and above on MSK Intensity scale

Zone IV: High Damage Risk Zone liable to seismic intensity VIII on MSK Intensity scale

Zone III: Moderate Damage Risk Zone liable to seismic intensity VII on MSK Intensity scale

Zone II: Low Damage Risk Zone liable to intensity VI or less on MSK intensity scale

7.4 Each of the above-mentioned zones is reasonably expected to have earthquake shaking of more or less same maximum intensity in future. The maximum seismic ground acceleration in each zone cannot be presently predicted with accuracy either on a deterministic or on a probabilistic basis. The basic zone factors included in the code are reasonable estimates of effective PGA for the design of various structures. Under GSHAP programme, PGA was also estimated and it shows good correspondence with existing Seismic Hazard of the region. The regions away from the Himalayas and other inter-plate boundaries were previously considered to be relatively safe from the devastating impact of earthquakes. However, the Koyna earthquake of 1967 and the Latur earthquake of 1993 dispelled this widely held view and influenced the revisions of the seismic zoning map.

7.5 According to the latest seismic zone map of India about 59 per cent of India's land area is vulnerable to moderate or severe seismic hazard, i.e., prone to shaking of MSK intensity VII and above. In the recent past, most Indian cities have witnessed the phenomenal growth of multi-storied buildings, super malls, luxury apartments and social infrastructure as a part of infrastructure development. The rapid expansion of the built environment in moderate or high-risk areas makes it imperative to incorporate seismic risk reduction strategies in various aspects of urban planning and construction of new structures.

Figure 3: Seismic hazard zonation map of India (Source: IMD/BIS)

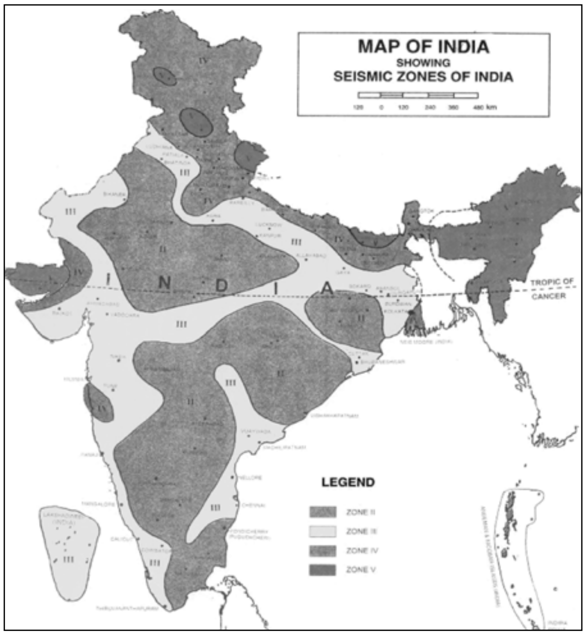
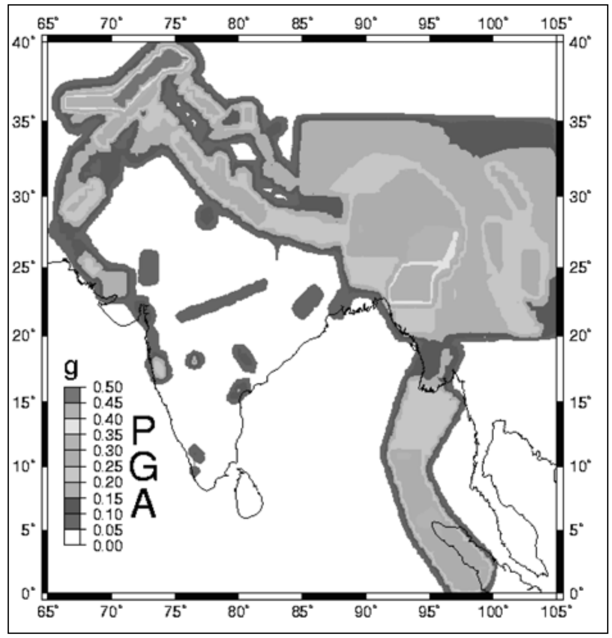


Figure 4: Seismic hazard map of India and adjoining regions, prepared under GSHAP programme.



7.6 Subsequent to Bhuj earthquake of 2001, Govt. of India has initiated a number of significant measures for earthquake hazard mitigation as mentioned, but not limited to, in the following:

- National Disaster Management Guidelines have been developed for Management of Earthquakes
- National Core Group for Earthquake Risk Mitigation has been formed.
- Urban earthquake vulnerability reduction project has been initiated in 38 cities in seismic zones 3, 4 and 5 with more than half million population each
- Earthquake safe construction guidelines for masonry buildings in different zones have been provided.
- Review of building bye-laws and their adoption has been initiated and model amendment in town and country planning legislations, regulation for land use zoning and building byelaws for structural safety have been suggested.
- Retrofitting of lifeline buildings including earthquake safety analysis for lifeline buildings in Delhi has been initiated.
- Various national level training and education programmes for capacity building in seismic resistant construction have been initiated at different levels for engineers, architects and masons.
- National Earthquake Risk Mitigation Project has been initiated
- A National School Safety Programme has also been initiated

Nepal

8.1 Nepal lies within the tectonically active Himalayan belt and occupies about one third of the Himalayan arc. The presence of three main fault lines: the Main Central Thrust (MCT) at the foot of the Greater Himalaya joining the midland mountains, the Main Boundary Fault (MBF) at the junction of the Lesser Himalaya and the Siwaliks and the Himalayan Frontal Fault south of the Siwaliks, each running east to west, are the main causes of earthquakes of small and great magnitude in Nepal. History of earthquakes in Nepal could be traced back to 1255 AD when one third of population of Kathmandu was devastated with heavy losses of human population, residential buildings and temples. One of the most devastating earthquakes in the recent past was that of 1934(M8.3) when about 8519 people died, out of which 4296 died in the Kathmandu valley alone. Over 200,000 buildings and temples were destroyed. The latest Udaypur Earthquake of 1988 killed 721 people, jolted 22 districts of Nepal and caused a direct infrastructural loss of 5 billion rupees. This earthquake became an eye opener in the country and the earthquake disaster was considered a major concern for the first time. Both the earthquakes of 1934 and 1988 caused devastation in India as well.

8.2 Several studies have been carried out by earth-scientists and seismiologists on earthquakes in Nepal Himalaya and large amount of data has been generated. A recent study of UNDP/ BCPR in 2004 has ranked Nepal as the 11th most earthquake risk prone country in the world. According to GSHAP data, Nepal lies in a region with high to very high seismic hazard. Historically, several earthquakes in the M6.0-7.0 range have taken place and at least two in the M7.5-8.0 range were experienced in 1833 and 1934 respectively.

8.3 According to past experiences and estimates by seismologists, Kathmandu valley has emerged as one of the hot spots of South Asia which is at a very high seismic risk, therefore, lot of studies have been carried in the recent past. Kathmandu Valley Earthquake Risk Management Project (KVERMP) by the National Society for Earthquake Technology (NSET) in association with Geo Hazards International (GHI), USA revealed that in the event of a possible repeat of the 1934 earthquake in modern-day Kathmandu Valley, a minimum of 22,000 and maximum of 40,000 human deaths could occur. A detailed study on earthquake disaster mitigation in the Kathmandu Valley was carried out by Japan International Cooperation Agency (JICA) in collaboration with the Ministry of Home Affairs and several other Nepalese institutions. It provided a detailed assessment of seismic vulnerability and damage analysis for existing buildings and public facilities; and it also gave an account of lifeline networks, including human casualty figures, for different earthquake scenarios in 2001-2002. Attempts have also been made on microzonation in Kathmandu as well as Pokhra valley. Significant attempts have been made to generate awareness and train manpower for building seismic resistant buildings in Nepal particularly in Kathmandu valley by various agencies such as NSET, National Seismological Centre (NSC), Govt. of Nepal and Khowpa Engineering College.

8.4 The Department of Mines and Geology (DMG) of the Government of Nepal with two independent recording centres - the National Seismological Centre (NSC), Kathmandu, and the Regional Seismological Centre (RSC), Birendranagar - has developed reasonably good seismic network and capability to detect any earthquake of magnitude as low as two on the Richter scale in any part of the country. It regularly updates information on website.

Pakistan

9.1 Large tracts of Pakistan lie within a seismically active Himalayan belt. Within Suleiman, Hindu Kush and Karakoram mountain ranges, the northern areas, Chitral districts in NWFP, Parts of Kashmir, Quetta, Chaman, Sibi, Makrana coast and parts of Balochistan are located in high or very high risk areas. Cities of Islamabad, Karachi and Peshawar are located on the edges of high risk areas. Five major earthquakes have hit Pakistan including: 1935 Quetta earthquake, 1945 Makrana coast earthquake, 1976 Northern Areas, 2005 Kashmir earthquake and most recently 2008 Balochistan earthquake. Geological Survey of Pakistan in 1974 prepared a map of seismic intensities and earthquake hazard zones of Pakistan. As per the latest seismic zoning map, the country has been divided into four seismic hazard zones based on the Earthquake data (historical and instrumental) and observed intensities.

Zone-I: Very high hazard zone with Seismic Factor ranging from g/5 to g/10. This zone is liable to major damage due to earthquakes.

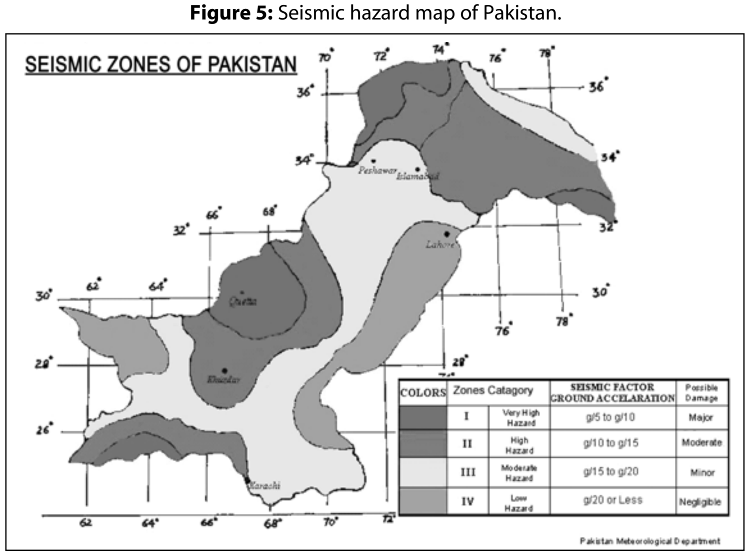
Zone-II: High Hazard zone with Seismic Factor ranging from g/10 to g/15. This zone is having a possibility of moderate seismic damage.

Zone-III: Moderate hazard zone with Seismic Factor ranging from g/15 to g/20. This zone may experience minor damages due to earthquake.

Zone-IV: Low hazard zone with Seismic Factor equal to g/20 or less. This is the safest zone with negligible expected damage.

9.2 According to GSHAP data, Pakistan lies in a region with moderate to high seismic hazard; the greatest hazard is in parts of the North West Frontier Province (NWFP), in the vicinity of Quetta and along the border with Iran. Historically, earthquakes in the M7.0 range have been experienced in Balochistan and along the border with Afghanistan and India. Recent earthquake around Balochistan has once again revealed the vulnerability of the region. In a recent study, Roger Bilham has highlighted the vulnerability of Karachi with a population of 14 million.

Figure 5: Seismic hazard map of Pakistan.



9.3 The loss of life and property and the challenges that were faced in the aftermath of 2005 Kashmir earthquake paved the way for establishing one of the best institutional arrangements to reduce losses from disasters in future. Various mitigation measures and loss reduction strategy have been implemented during reconstruction and rehabilitation of earthquake affected region. Recently a collaborative study between Pakistan Meteorological Department and NORSAR, Norway has produced estimates of the ground motion parameters at a site for the purpose of earthquake resistant design or seismic safety assessment. The experiences gained while managing the disaster of 2005 has not only taught a very valuable lesson to authorities as well as public in Pakistan but also it is an eye opener for entire South Asia.

Sri Lanka and Maldives

Figure 6: Tsunami hazard zones of Maldives (Source: USAID)

10.1 Sri Lanka lies in a region of low seismic hazard. Historically, mild earthquakes have been experienced in different parts of the island. Onshore hazard is low but earthquakes in the M5.0-6.0 range have occurred in the Gulf of Mannar in historical past that were felt all over Sri Lanka. M7+ events originating in the Sumatra-Andaman arc and events in the M6 range originating in the north Indian Ocean have also been felt. Although Sri Lanka is far away from the plate boundaries, yet it is close enough to the highly active seismic zone near Sumatra and other regions to its South-East so that earthquakes generated in these region may lead to a Tsunami Hazard in Sri Lanka as experienced during the 2004 event that devastated much of the east and south coasts, claiming more than 35,000 lives and displacing over half a million people.

10.2 Similarly, although the Maldives enjoys very low seismic hazard in terms of ground shaking, it remains one of the most vulnerable country to tsunami effect due to major earthquakes in the Indian Ocean as it was severely affected by the 2004 tsunami. Tidal waves ranging from 1.2 to 4.2 meters swept across most parts of the country. Out of the 198 inhabited islands, 13 were rendered not habitable, 56 sustained major physical damage, and 121 were impacted by moderate damage due to flooding. Over 100 people were killed and more than 6000 houses were either destroyed or severely damaged

Gaps in Seismic Risk Assessment

11.1 The entire Himalayan-Hindukush region is considered to be vulnerable to earthquakes of a magnitude exceeding 8.0 on the Richter Scale, and in a relatively short span of time, six such earthquakes have occurred: Shillong, 1897(M 8.7); Kangra, 1905 (M.8.0); Bihar-Nepal, 1934 (M 8.3); Assam-Tibet, 1950 (M 8.6); Quetta, 1935 (M 7.8); and Kashmir earthquake, 2005 (M 7.6). Scientific publications have revealed that very severe earthquakes are likely to occur anytime in the Himalayan Region, which could adversely affect the lives of several millions people in the region. It is important to note that the urban population of South Asia is anticipated to touch 750 million by 2020 from 400 million at present, thereby almost doubling the risk to urban population in high hazard areas across Afghanistan, Pakistan, India, Nepal, Bhutan and Bangladesh.

In the recent times, additional knowledge and information have been acquired with respect to seismicity in Himalayan belt as well as in Indian sub-continent which is of great relevance for proper hazard assessment and initiating mitigation measures.

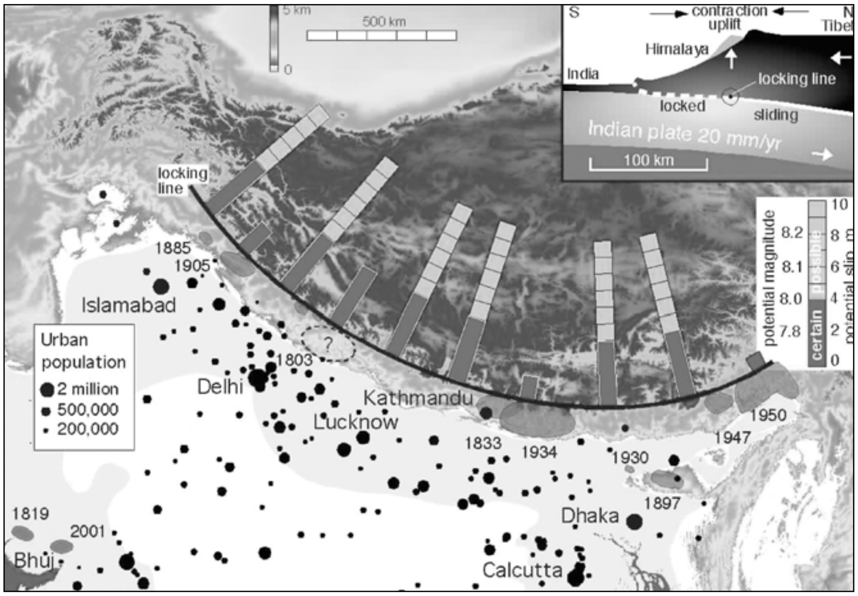
11.2 In one such study Bilham et al. (2001) estimated slip potential along the Himalaya and interpreted it in terms of seismic hazard in the region. In Figure 7, the red segments along the bars show the slip potential on a scale of 1 to 10 meters, that is, the potential slip that has accumulated since the last recorded great earthquake, or since 1800. The pink portions show possible additional slip permitted by ignorance of the preceding historic record. The bars are not intended to indicate the locus of specific future great earthquakes, but are simply spaced at equal 220-km intervals, the approximate rupture length of the 1934 and 1950 earthquakes. Black circles show ever growing population centers in the region; in the Indo-Gangetic Plains, the region extending ~300 km south and southeast of the Himalaya, the urban population alone exceeds 40 million. The inset figure shows simplified cross section through the Himalaya indicating the transition between the locked, shallow portions of the fault that rupture in great earthquakes, and the deeper zone where India slides beneath Southern Tibet without earthquakes. Bilham concluded the study with the following projection:

"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".

11.3 The Himalayan seismic belt constitutes one of the largest seismic belts of the world, but many aspects of seismicity in the region are yet to be studied and investigated. This calls for cooperation among the scientific and technical institutions of the region for more comprehensive assessment of earthquake risks on the basis of which various mitigation measures at the local level can be initiated by the national and local governments. This may include but not limited to the following issues for regional cooperation.

11.4 **Upgradation of seismic network*:*** In order to assess the attenuation characteristics of recent earthquakes in different media and topographical as well as geological set up, it is essential that seismic network of the region needs to be strengthened particularly in most heterogeneous terrain across Himalaya. In view of the earthquake of recent past in Indian peninsula region, such areas are also required to be densely instrumented for recording ground motion due to earthquakes. Towards this, various national governments such as

Figure 7: Slip potential as a major of seismic hazard along Himalaya



Pakistan, Nepal, India and Bangladesh have made significant progress such as initiating national programmes to augment the seismic net work. At the national level improved seismic networks will enable assessment of damage potential at different locations. Efforts at national level could lead to prioritization of areas for seismic microzonation and better urban planning. Due to the regional proximity and continuity of the seismic belt, it is essential that a regional consensus may be reached on selection of sites at reasonable spatial interval where such instruments can be installed and data that is generated are shared among all countries through the SAARC Disaster Management Centre.

11.5 **Advanced Seismic Hazard Assessment:** The regional efforts on seismic hazard assessment must focus on recent assessment of seismic hazard/vulnerability/risk in the region, networking of seismic stations, sharing pre-existing seismic data and adoption of state-of-art approach for zonation and micro-zonation. The understanding of inter-plate as well as intra-plate seismicity has undergone sea change in recent times due to advancement of seismological observation and synthesis. Therefore, there is an urgent need to incorporate the results of advance research in mitigation measures so as to develop "Resilience through Research".

11.6 **Updation of Seismic Hazard Maps:** Country specific as well as regional efforts are required for updation of Seismic Hazard Maps by incorporating the history of recent earthquakes, their damage characteristics and recently acquired scientific knowledge through cutting edge research published in reputed scientific journals. This can be achieved by referring to updated seismo-tectonic map, active fault map and recent geomorphological changes, micro-seismicity, strain rates, geotechnical investigation and palaeo-seismicity of the region. Based on this updated hazard map, attempts must be made on development of vulnerability and earthquake risk maps.

11.7 **Liquefaction Susceptibility Analysis:** Liquefaction is one of the most important seismic hazards already experienced during the past earthquakes and most recently it caused maximum devastation during Bhuj earthquake of 2001. Liquefaction potential assessment in most of the low lying areas with soft sediments and shallow water table that could experience low shear wave velocity and higher spectral amplification during earthquake even originating at far off locations needs to be undertaken in hazard prone zones. Infrastructure exposure to liquefaction hazard needs to be analysed for minimizing the damaging effect. Assessment of infrastructure development in such vulnerable areas with seismic resistant provision will be an important hazard mitigation measure. For example during 2001 Gujarat earthquake many roads and railway tracks as well as earth dams developed cracks due to liquefaction. Similarly during 1934 Nepal-Bihar earthquake, many places in Nepal and north Bihar experienced liquefaction that could lead to subsidence, settlement and tilting of structures. In the recent past during 2005 earthquake many places in Kashmir experienced liquefaction that could lead to subsidence, settlement and tilting of structures. Places as far as Jammu at 225 km distance from the epicenter also developed liquefaction cracks. Therefore, liquefaction needs to be analysed with respect to expected ground motion, geomorphological characteristics including age of the sediments and grain size, water table and past history of liquefaction.

11.8 **Seismicity Induced Landslides:** Numerous seismicity induced landslides have caused immense damage during past such as 1998 Afghanistan earthquake, 1991 Uttarkashi earthquake, 1999 Chamoli earthquake, 2005 Kashmir earthquake and more recently during 2008 Sichuan (China) earthquake. Landslides burry habitats, infrastructures, and can dam a river and form a reservoir that can be a potential danger in case of breach. Such hazards have caused havoc in the past. In Pakistan, during winter of 1840 and early 1841, part of the Nanga Parbat collapsed into river Indus following an earthquake. The landslide dam formed a 305 m deep and 64 km long lake. The dam was breached in June 1841 and hundreds of villages as far as Attock at 400 km downstream were washed away and 500 soldiers camping on the flood plain near Attock were killed. Additionally, monitoring of major cracks and joints developed either by low magnitude or high magnitude events need to be monitored as these have potential to cause huge landslides during monsoon period in subsequent years. This has been already experienced during the earthquake of 2005 and in subsequent years in many parts of Kashmir. Therefore, steep hill slopes of the Himalaya on fragile rocks must be assessed for potential landslides in the event of earthquakes.

11.9 **Seismic Microzonation:** The quantification of earthquake risk for a specific area requires detailed information on a number of factors, including seismo-tectonics, geology and topography of the area, characteristics of surface deposits and site effects and typology of the construction. Seismic micro-zonation provides such information at a local level for determining the seismic safety of buildings and structures, by analysing the existing land use plans, and revealing the seismic threat to the stakeholders. Seismic microzonation and site response study are therefore, required on large scale to assess the seismic hazard potential at city level and preparation of suitable development plan. The damage pattern of some of the recent earthquakes demands that microzonation needs to be carried at city level to determine the most vulnerable pockets of a city, so that suitable measures can be taken either for retrofitting of existing buildings or construction of new buildings. It will provide most crucial information on spectral amplification and liquefaction. Realising the importance of the information, various national governments have initiated studies on seismic microzonation in mostly mega cities of respective countries. For example, recently microzonation have been attempted for Dhaka and Sylhet cities of Bangladesh. In India microzonation has been attempted at selected cities such as Jabalpur, Delhi, Dehradun and Gandhinagar. Attempts have also been in Kathmandu and Pokhra to assess the seismic vulnerability at city level. Microzonation studies of all the metropolitan cities in seismic zones should be taken up in a phased manner through increased collaboration among scientific and technical organizations and municipal authorities of the region.

Earthquake Risk Mitigation

12.1 Earthquakes do not kill, but collapse of building does. Therefore the entire focus of earthquake risk mitigation should be on strengthening the buildings and other infrastructure through various structural and non-structural mitigation measures that can withstand the shocks of earthquake. This by no means is an easy tasks, as millions of buildings have already been constructed that do not conform to earthquake resistant standards and hundreds of new buildings are coming up that do not conform to the standards. The countries have made some progress in developing earthquake resistant building codes, but enforcement of these codes is a huge issue as most of the construction takes place on individual initiatives without sanctioned building plans and even if the plans are sanctioned actual construction does not take place as per approved standards. Constructions can not be made earthquake resistant merely by revising the building codes, which can at best be a starting point. The engineers, architects and masons must have the capacity to understand and implement the codes. The municipal authorities must have the capacity to enforce the codes. More importantly a massive awareness about the importance of complying with the codes must be developed so that people adopt the codes voluntarily for their own interest. While some good works have been done specially in areas that had faced earthquakes, but these experiences must be transferred to other places through training and awareness generation programmes and sharing of good practices across countries in the region. Various mitigation measures that can be promoted through regional cooperation.

12.2 **Earthquake resistant design and construction:** Collapse of structures like houses, schools, hospitals, roads, dams, bridges and other buildings account for nearly 90% of deaths, injuries and damages in earthquakes. Therefore, earthquake resistant design and construction must be emphasised, promoted and integrated in infrastructure development. The designs of all new buildings and structures may be scrutinised by the competent authorities through a general compliance review and mandatory technical audit process by qualified professionals. A detailed peer review or third party audit of the design and construction of major construction works may be undertaken by qualified accredited agencies for ensuring compliance with the techno-legal regime. In this regard it is essential to develop and promote awareness about national building codes and sample designs of house, high-rise buildings and infrastructure (bridges, roads) for safer construction in hazard prone rural and urban areas.

12.3 **Building codes, Regulation and Enforcement:** All countries of South Asia are going through a phase of rapid development and housing is identified as one of the priority sectors. Therefore, building by laws and building codes are going to play a major role in ensuring the high quality of construction, particularly in earthquake prone areas. This is more so in case of Afghanistan, as the country is going through a phase of massive reconstruction. Recently, in Nepal, building codes have been proposed for implementation. Similarly in India, attempts have been made to popularize the adherence and enforcement of building by laws on earthquake resistant designs. Bangladesh is also attempting on promotion of building codes. In Pakistan, it has been suggested to promote building codes in major urban areas. Most importantly, rural and semi-urban areas account for most of the total building stock in South Asia. The construction of these structures is presently unregulated and is adding to the numbers of vulnerable structures. Specific illustrative guidelines may be issued for each non-engineered construction type in earthquake-prone areas and demonstrated through the construction of new public buildings in villages. For instance, the buildings of post offices, primary schools and primary health centres in rural and semi-urban areas may be used as demonstration buildings.

12.4 Review of existing building codes and improvement thereon and finalization of new building codes for construction of earthquake resistant buildings in different zones as per the level of hazard is one of the most important priorities to minimize the risk level. In the absence of appropriate building codes, new building codes need to be developed at the earliest. Care must be taken to ensure that the building codes are in coherence with the traditional architectural perception of the local population. Governments should establish necessary techno-legal mechanisms to ensure that all stakeholders both in public and private domain like builders, architects, engineers and government departments implement building codes for adequate seismic safety in all designs and construction activities.

12.5 **Retrofitting of Priority Structure:** The requirement to improve the ability of an existing building to withstand the ground shaking due to earthquake requires retrofitting of the structure that must be carried out in a phased manner by drawing priorities like buildings of national importance, lifeline buildings, public utility structures, multi-storied buildings, etc. It is important to note that during Kashmir earthquake of 2005 and Sichuan earthquake of 2008, large number of school children died due to collapse of school buildings; therefore, on priority such buildings need to be retrofitted to minimize casualty. The selection of such buildings may be based on considerations such as the degree of risk, the potential loss of life and the estimated financial implications for each structure, especially in high-risk areas. The seismic vulnerability and risk profiles of buildings can be established by Rapid Visual Screening (RVS) and Detailed Vulnerability Assessment (DVA). The former is a quick estimation with visual observation through multi-angle video and prior information about the construction methods and age of the building to determine whether the structure is vulnerable or not. Once the RVS identifies a structure to be vulnerable, then it may be subjected to a detailed assessment for a quantitative evaluation of vulnerability. As a general strategy, seismic retrofitting of the existing built environment requires a systematic and sustained effort, by carrying out several activities as mentioned:

a. Developing an inventory of the existing built environment.
b. Assessing the vulnerability of these constructions.
c. Prioritising structures found vulnerable.
d. Developing seismic retrofitting measures.
e. Strengthening vulnerable structures.

12.6 In this regard important issues such as cost estimate of retrofitting, types of materials and methods required for undertaking modifications/ enhancements of existing structural elements, the time required to complete the retrofit of a particular size and type of building, and the artisans who have the proficiency in seismic retrofitting, etc., may be addressed in collaboration with the nodal agencies and professional organisations. In consultation with these agencies, a standardised procedure for vulnerability assessment and retrofitting thereon may be prepared at the national level to generate awareness to improve the seismic standard of important buildings in line with the relevant national standards. In order to popularize the concept among people and private sector, wherein most of the built environment is constructed, emphasis must be laid on low cost, affordability and easy to execute by demonstrated examples. However, it must be kept in mind that the cost of retrofitting is much higher than construction as per building codes, therefore, safe and better construction with an additional cost of 10-20% should be promoted to safeguard the present investment and precious human lives.

12.7 **Promotion of Indigenous Technology:** South Asia has rich reservoir of indigenous knowledge of building materials and construction technology that has withstood the test of time. Such buildings practices are not only cost effective and thermally efficient these also conform to the culture and way of life of the local communities. Many of these technologies have the danger of becoming extinct due to their neglect and promotion of concrete buildings by the engineers and architects. Many such indigenous earthquake-resistant housing technology and practices like the *bhongas* in the Kutch Region of Gujarat, *dhajjidiwari* buildings in Jammu & Kashmir, *brick-nogged* wood frame constructions in Himachal Pradesh and *ekra* constructions made of bamboo in Assam and similar construction methods in Nepal and other countries needs to be promoted. In recent times the indigenous practice of light weight, timber-laced construction has given way to more massive masonry and reinforced concrete construction which provides inadequate protection against harsh winter in hilly areas of Pakistan, India, and Nepal but is often poorly constructed to withstand strong earthquakes. It is very essential to apprise communities to ensure the seismic safety of the built environment by encouraging the use of simple, easy and affordable technical solutions and institutional arrangements.

12.8 **Capacity Building:** Capacity building measures need to be implemented through training and education at various levels by making use of the expertise and infrastructure available at national/international organisations. The earthquake education may be included in the educational curricula starting from school level and high quality educational materials need to be developed to address various aspects of earthquake management, like preparedness, mitigation and response. Special training programmes need to be developed for various target groups such as public representatives, Government officials, urban planners, engineers, architects, masons, builders, NGOs, community based organizations (CBOs), social activists, school teachers and school children. Special emphasis must be given to introduce/ expand topics in disaster management in training module of armed forces and civil administration as these are the agencies most involved in disaster management. Strategies must be made to upgrade skills of professionals and skilled work force to implement earthquake risk mitigation measures. Education and training programmes may be designed, with greater attention on developing the capacity and skills of trainers and trained teachers. Appropriately designed science and technology courses may be introduced to orient all target groups including school teachers and health professionals in the subject.

12.9 Most importantly, all architecture and engineering graduates need to be equipped with the requisite knowledge of earthquake-resistant design and construction techniques. The mainstreaming of earthquake management in development planning may be supplemented with the development of the requisite infrastructure in technical and professional institutions, improved laboratories and libraries in knowledge institutions and R&D institutions. These measures may enable them to undertake research, execute pilot projects, and develop resource materials and technical documents for education, sensitisation and training programmes. In order to replicate successful research such as advance hazard analysis, microzonation, risk simulation, earthquake scenario analysis, necessary networking of research organizations and line departments must be established and transfer of technology/methodology must happen through participatory (hand holding) approach involving mid-career intervention of professional staff of line departments.

12.10 **Awareness:** Awareness on improved understanding of seismic hazard for better preparedness among communities and to invoke and share indigenous knowledge for various mitigation measures based on success stories and lessons learnt from the region would be of immense value in any disaster mitigation strategy.The earthquake vulnerable communities need to be educated on earthquake safety measures in the construction of residential structures at a nominal additional cost. It is envisaged that as a sense of security the civil society would automatically incorporate seismic resistance measures for stronger residential complexes. Visual aids on earthquake safety must be prepared in local languages for the general public to increase awareness about earthquake safety and generate demand for earthquake safety standards. Audio-visual programmes may also be required for creating awareness about the seismic hazard and preparedness. Awareness programs may be organized by Governmental and Non-Governmental Organizations for specific target groups of stakeholders on seismic hazard mitigation. Mass media (TV, Newspaper, Radio), Film / slides, Pamphlets/Posters etc., Poetry/Debate/ Essay competition, workshop/conferences need to be organized to generate awareness among masses. Specially designed public awareness programmes may be developed for addressing the needs of physically handicapped and mentally challenged people, women and the elderly.

12.11 Early warning and Precursors of Earthquake: At present level of research although it is not possible to provide early warning for earthquake like in case of cyclone or flood, however, attempts are being made to assimilate various precursors of earthquake. Such precursors can provide valuable information, which can be very useful for providing early warning. The following are some of the important precursors that needs to be monitored and assessed in an integrated manner to provide early warning or some lead time to act in the event of an earthquake. Attempt must be made to reduce false alarm and aware public about the utility of such alarms. At the present level of development, the following precursors can be used to be alert and better prepared to face the earthquake event.

12.12 Earthquake foreshock is one of the important precursors that are being monitored at various high risk areas to provide early warning. Although not all major earthquakes are preceded by foreshocks, in some cases it has been observed, therefore, needs to be observed and considered for issuing early warning. In one such example, the existence of foreshocks made possible the most important earthquake prediction of recent times-the Chinese order to evacuate the city of Haicheng prior to M=7.4 earthquake of Feb. 1975. A series of small events occurred immediately prior to man shock, and, when the earthquake struck, most of the population had left and very few lives were lost.

12.13 Early detection of P-wave is an important precursor as it travels faster than the more destructive surface waves and depending on the distance of epicenter, soil conditions, depth of the earthquake etc, there could be 10-50 seconds lead time to take life saving measures. This might not seem like a long time, but in just seconds occupants could wake up their children and find a safe location, away from sharp and heavy objects that could injure them! Commercially such instruments are available at a nominal cost of US$ 100-200.

12.14 Observation of ground deformation through GPS and InSAR as well as several other ground and satellite based observation for thermal and other anomalies can provide very valuable precursory information. A remote sensing based thermal technique has been employed recently by seismologists, based on the concept that stress accumulated in rocks in tectonically active regions may be manifested as temperature variation through a process of energy transformation. Land surface temperatures (LST) were observed to rise before an impending earthquake using pre- and post-earthquake datasets of thermal sensors of satellites for different regions. However, this kind of rise in LST could also be due to other factors as well atmospheric factors, therefore, needs further experimentation and validation.

12.15 On a significant number of occasions, satellites have picked up disturbances in ionospheric part of the atmosphere that have later been hit by earthquakes. One of the most important of these is a fluctuation in the density of electrons and other electrically-charged particles in the ionosphere, that can be detected by satellites, however, still it is a topic of research and further studies are required to conclusively use inospheric disturbance as a precursor.

12.16 Attempts are also being made to monitor abnormal animal behavior such as restlessness of reptiles and dogs and use as precursors to earthquake. It has been observed that there could be sudden rise or fall in water level in the wells. It could be as high as one metre. Sometimes the well water may turn muddy. At times a fountain appears inside the well. All these changes happen about one or three days before the earthquake. Sometimes a fountain appears in the ground. This normally happens a few hours before the quake. Other possible precursors that have received wide attention are changes in seismic pattern, variation in the pattern of radon gas emission, and electromagnetic anomalies. However, many papers have appeared supporting and opposing these views. Therefore, as discussed, precursors and satellite based observations despite limitations, have potential to be used in early warning and it is necessary that routine observation and multi parametric approach need to be followed in high risk areas.

12.17 **Finance and Insurance:** With increasing dependence on assistance from financial institutions due to rise in real estate and construction cost, new opportunity has arisen to implement seismic resistant design and seismic retrofitting of the critical and lifeline structures as a mandatory condition of any financial assistance scheme. Special financial schemes with incentives such as tax exemption should be available for housing societies and vulnerable communities to implement retrofitting/ seismic resistant design. Secondly innovative insurance products such as indices based products can act as a catalyst to improve the building resistance. Suitable micro finance schemes need to have flexible repayment schedules for recipients who have been affected by disaster.

Earthquake Preparedness

13.1 Having assessed the vulnerability, risk and taking feasible mitigation measures as mentioned above, the communities and state need to prepare for the acceptable risk in the event of an earthquake. It is expected that, each vulnerable region would have a Disaster Management Plan and responsible organizations need to be identified. Preparedness will begin with the formulation of family and community contingency plans, which need to be adopted through mock drills at schools, hospitals, offices, and industrial units. In large metropolitan cities, special preparedness plans must be made for malls, cinema theaters, auditoriums, community centers etc. At all such places, emergency managers need to be designated, trained and given charge of implementing emergency response activity. Volunteers groups, NGOs, social organizations, religious leaders, and political representatives need to be involved in preparing and implementing community based DM plans.

13.4 The DM plans prepared at district and province level should have a Medical Preparedness Plan to improve emergency medical response. Medical preparedness plan should focus on likely injuries, verification of stock inventories of medicines and surgical equipments, readiness of x-ray machines and ambulances, outbreak of diseases and other post-earthquake public health problems. Mock drills at regular interval (at least once in 6 months) must be carried out for rehearsing preparedness.

Earthquake Response

14.1 The management and control of the adverse consequences of future earthquakes require coordinated, prompt and effective response systems at various levels in the government and at the community. Many of the components of response initiatives are the same for different types of disasters and therefore standard emergency protocols need to be developed considering the multi-hazard scenario of various regions in order to optimally utilise available resources based on Disaster Response Plan (DRP).

14.2 The response mechanism encompasses various efforts related to severity assessment, search and rescue, relief, rehabilitation and reconstruction. Numerous lessons can be learnt from experiences from 1998 Afghanistan earthquake, 2001 Bhuj earthquake (India) and 2005 Kashmir earthquake and all these experiences must be ploughed back into a much more effective response mechanism. Recently based on Tsunami as well as earlier experiences, "Cluster approach" is being advocated by UN agencies wherein a single agency will be given lead responsibility to act in one of the nine areas of operation such as health, nutrition, communication, water & sanitation, logistics, camp management, emergency shelters, telcom, and protection of vulnerable groups.
Incident Command System: All response activities may be undertaken at the local level through a suitably devised ICS coordinated by the local administration. Governments may commission and maintain Emergency Operating Centers (EOCs) at appropriate levels for the coordination of human resources, relief supplies and equipment. SOPs for the EOCs may be developed by governments and integrated within the framework of the ICS, which will take advantage of modern technologies and tools, such as GIS maps, scenarios and simulation models for effectively responding to disasters. GIS maps available from all sources may be compiled considering their potential application during relief management. Based on local requirement, on site maps need to be produced by trained professionals.

14.3 Deployment of Trained community level teams is an important task that must be accomplished within shortest possible time to assist in planning and setting up emergency shelters, distributing relief among the affected people, identifying missing people, and addressing the needs of education, health care, water supply and sanitation, food etc., of the affected community. Members of these teams may be made aware of the specific requirements of the disaster affected communities. These teams may also assist the government in identifying the most vulnerable people who may need special assistance following an earthquake.

14.4 **Severity Assessment:** In the event of earthquake, the assessment of severity of an earthquake is the most important priority and is often marked by uncertainty during the first few hours of occurrence. The preliminary assessment of severity of the earthquake is based on its magnitude and depth collected from online seismological instruments. Field observation data, once available, can be used to make an accurate assessment, however, there is a time lag and it is often observed that considerable amount of precious "Golden Hour" (first few hours) is lost by the time clear picture about damage pattern emerges. Therefore, immediately following the occurrence of an earthquake, the concerned agency should disseminate the details of its magnitude and epicenter to all agencies concerned. At the same time, it should trigger research/professional organizations to model and simulate damage pattern based on priori information on attenuation and expected ground motion. This will help the government departments to undertake their response appropriately based on spatial extent and magnitude of disaster. However, this requires considerable investment in advance research and development and therefore, must be taken as a priority parallel action.

14.5 **Search and Rescue:** S&R mechanism constitute the most immediate action component of response mechanism and need to be well organised in terms of transport logistics (air and road), instruments, power back up system, expertise, dedicated manpower and communication system. All equipments must be stored at well identified place in high risk areas and within shortest possible time manpower as well as machines must be deployed at priority areas. Supplier of critical equipments such as concrete cutters and heavy earthmoving machinery must be identified and long term arrangements for their mobilisation and deployment must be worked out in the event of an earthquake.

14.6 The community in the affected neighbourhood is always the first responder after any disaster. Experience has shown that over 80 per cent of search and rescue from collapsed buildings is carried out by the local community before the intervention of the state machinery and specialised search and rescue teams. Thus, trained and equipped teams consisting of local people may be set up in earthquake-prone areas to respond effectively in the event of an earthquake. Search and rescue mechanism need to be backed up well by onsite as well as offsite medical response and counselling arrangements for relatives of trapped population.

14.7 **Medical response*:*** Prompt and efficient emergency medical response may be provided through mobile field hospitals and heli-ambulances. They may be activated to reach the earthquake affected areas immediately, along with dressing material, portable X-ray machines, mobile operation theatres, resuscitation equipment and life-saving drugs, etc. Trained Medical First Responders (MFRs) for administering first aid and resuscitation measures, at the incident site and during transportation of victims need to be activated and deployed. Earthquake victims often come with injuries related to orthopaedics, excessive bleeding, haemorrhages and trauma. Expected mothers, aged and children require special assistance, therefore such gender and age related concern must be addressed in the Medical Response Plan (MRP). MRP should also include Mass Casualty Management Plan. Each health centre and major hospitals must be fully equipped in terms of medicine and additional deployable doctors and health workers. There must be a roster system, by which in the event of disasters, additional manpower must be deployed in an automatic manner from adjoining areas. Hospitals in the affected areas may create a surge capacity for the required number of beds by discharging non-critical patients and mobilize doctors and support staff, additional orthopaedic equipment and supplies at short notice. There must be assessment of capacity and travel time between important hospitals to distribute victims evenly in shortest possible time. Local specific arrangements must be made to carry the injured. For example, in hilly area, special type of stretchers must be designed to bring the injured from inaccessible areas to road head. After an earthquake, information centres may be set up to provide medical response information to the public, relatives of victims and media. Psychosocial and physiotherapy support and trauma management needs to be addressed to enable the affected population recover quickly from the disaster. Disease early warning system, provision of safe drinking water, immunisation, malnutrition and burns cases needs to be addressed particularly in relief camps.

14.8 **Relief Management:** Target population and area must be identified on the basis of severity and need; beneficiary consultation and participation is essential for effective targeting. For example, the poor are disadvantaged in recovery having limited access to resources, and fewer options for recovery, therefore, the focus should be pro-poor and disadvantaged. Based on the experiences gained during the past earthquake response in the region make it imperative that the following aspects of relief management need special attention in the regional context of South Asia.

- Monitoring of emergency responses and coordination between communities (to ensure community participation), NGOs, private sectors, international agencies and national authorities in relief distribution. Based on strength-weakness assessment, right combination of agencies must be identified for different tasks during different time period for better delivery in a credible manner.
- Selection of appropriate relief material based on culture and need of target population. In Bhuj, used cloths received as relief were mostly discarded by local population for cultural reasons. Similarly, milk powder was mistaken for washing powder as local practice and culture are different.
- Logistics arrangements need to be local specific, feasible, sensible, effective and operable. In hilly areas animal transport although primitive is most effective as human settlements are scattered and due to stiff topography air dropping is not feasible always. Therefore, a judicious combination of air dropping, motor transport and animal transport need to be incorporated in the response plan.
- Deployment of trained and committed staff at all levels of relief management by all stake holders such as NGOs, government and international agencies.
- There should be transparency in relief management by incorporating online inventory of collection and distribution of relief material.
- Procurement of goods through national and international community assistance needs to be handled professionally by proper need assessment, fund raising, local and international purchasing, collection and distribution old and used materials often play an important role in developing countries.
- Security of relief material, volunteers (particularly from international agencies) and vulnerable population need to be addressed.
- "Residual relief" after the main phase need to continue in a time bound manner.
- Suitable operating procedures need to be developed to fast track requests for aid and to facilitate deployment of international response teams, and receive relief goods.

14.9 **Relief Camps:** The response mechanism must address the issue of setting up of relief camps for the people whose houses have been damaged by an earthquake with adequate provision of basic amenities (community as well as gender specific) in such camps such as relief supplies, tents, water supply, sanitation, transport, communication systems, medical supplies, education and privacy. All types of relief camps such as planned, spontaneous and scattered need to be set up based on the requirement, advantage and choice of affected population.

14.10 **Information Dissemination/ media management:** Information dissemination/ media management plays a very crucial role after an earthquake, as it would restrict spreading of rumors and will provide authentic information to affected population as well as outside world about the extent of the damage and the details of the response activities. Advocacy and the media can play an important role in assessing the local need, adequacy, aspiration and educating local population on relief management. Governments may utilise different types of media, especially print, radio, television and Internet, to disseminate timely and accurate information on all aspects of response mechanism. It will enable two way communications such as providing the right information to all stake holders and receiving required information from donors and affected community about their requirement, which will play a crucial role in bridging the gap between demand and supply of relief materials and all types of assistance.

14.11 **Regional Response Mechanism:** In the Fifteenth SAARC Summit held in Colombo in 2008 the Heads of the States/Governments declared that a Natural Disaster Rapid Response Mechanism (NDRRM) shall be created under the aegis of the SAARC Disaster Management Centre (SDMC) to adopt a coordinated and planned approach to meet emergencies created by natural and manmade disasters. The operative part of the Declaration – *Partnership for Growth of Our People* - adopted at the conclusion of the Summit is reproduced as under:

"The Heads of State or Government expressed concern at the human loss suffered through natural disasters in the region and stressed the need for the timely provision of relief in humanitarian emergencies. In this regard they directed that a Natural Disaster Rapid Response Mechanism be created to adopt a coordinated and planned approach to meet such emergencies under the aegis of the SAARC Disaster Management Centre".

14.12 As a follow up of this Declaration, the SDMC organized two Expert Group Meetings in New Delhi with representatives of the Ministries of Foreign Affairs, Defence, Disaster Management and senior officers of Immigration and Customs Departments of the Member Countries to develop a draft agreement on natural Disaster Rapid Response Mechanism in the region. The draft agreement as developed is attached. Once ratified by all the Member States the SDMC shall have the responsibility of coordinating emergency relief during natural disasters, once such assistance is requested by any Member State. Based on this draft agreement a Standard Operating Procedure (SOP) is being developed.

14.13 As a further follow up the SDMC has organized a five day Regional Workshop on Emergency Relief Management with senior officers of the Member States engaged with relief management in the respective States. The Workshop shall also be attended by representatives of some of a few international organizations and professionals having specialized knowledge and experience on emergency relief management to review the existing arrangements of emergency relief management in the countries of the region; identify the strength, weakness and gaps in the existing system; and to develop common understanding and agreement on minimum standards of relief in the region. The Agreement on NDRRM and development of Minimum Standard of Relief shall strengthen regional cooperation on earthquake response in South Asia.

Earthquake Recovery and Reconstruction

15.1 Earthquakes create the highest risks of catastrophic damages. Recovering from the damages and destructions of earthquakes and reconstructing the lives of households, communities, cities and villages that involve multiple sectors - housing, infrastructure, livelihood, health, education, environment etc - have been one of the daunting tasks of disaster management. Wealth of experiences is available from the reconstruction efforts after many disasters around the world. There is a need to learn from these experiences, develop tools and methodologies for pre-disaster recovery planning and upgrade the knowledge and skill of all those stakeholders who would be involved in the assessment of damage and loss after disasters, planning of recovery and reconstruction and implementation of the plans in their different phases. SAARC Disaster Management Centre can play important role in documentation and sharing of such good practices in the region. Various steps for post-disaster recovery and reconstruction are discussed in the following paragraphs.

15.2 **Damage Assessment:** Post disaster damage assessment is the critical as well as very sensitive activity as most of the decisions related to reconstruction, rehabilitation, financial compensation would depend on such assessment. Therefore, it is imperative that such assessment be carried out in shortest possible time by deploying advance technological tools such as imaging from aero-space media and video coverage based rapid assessment tools supported by ground verification in coordination with all stake holders including the affected population. Data collection methodology and common reporting format need to be used for easy comparison and better assessment.

15.3 **Building Back Better:** Reconstruction should be envisaged as an opportunity for building back better so that reconstructed houses and infrastructure are able to withstand the shocks of future earthquakes. Safe houses lead to safe cities- this must be the underlying principle of any reconstruction programmes to be followed after an earthquake. Rebuilding should be linked to reduction in poverty as well as vulnerability by suitable site selection and appropriate construction as per the local requirement with locally available resources (manpower as well as material). Rehabilitation and reconstruction must be integrated into development planning of the region by suitably integrating both programmes.

15.4 **Business Continuity Planning:** Revival or survival of business activity is key to quick recovery of any region in the world after any major disaster. Communities cannot survive a disaster unless the economy survives. Small to medium-sized businesses are the backbone of the South Asian economy, but most do not plan for a major business interruption. Secondly, since it falls mainly in the private domain, often remains out of disaster mitigation strategy initiated by government agencies. Therefore, it is necessary to educate and motivate business owners as well government planners to develop plans, to recognize that business recovery is tied to community-wide disaster resistance and resilience, and to institutionalize business continuity planning into business practices and government planning process. Lessons must be learnt from what has made the difference between business survival and failure following a disaster. It is important to explore how business continuity planning, involvement with disaster-resistant and resilient community enhances its ability to survive, remain viable, and ultimately recover from a major disaster.

Issues for Regional Cooperation

16.1 Each component of earthquake risk management – risk assessment, risk mitigation, response, preparedness, recovery and reconstruction – provide enormous scope and opportunities for the countries of South Asia to cooperate with each other through the auspices of SAARC Disaster Management Centre. The SAARC Workshop on Earthquake Risk Management in South Asia has been organized to reach a common understanding in identifying the issues of regional cooperation and to develop a Road Map for regional cooperation on short, medium and long term framework based on which an Action Plan shall be developed for implementation. The idea is to develop collective wisdom and enrich the knowledge domain that will enhance overall capacity of the South Asia in terms of technology, coordination, sharing and implementation of seismic hazard mitigation strategies. The valuable knowledge and experience of domain experts from the member states as well as reputed operational and research institutions related to earthquake hazard assessment and mitigation will enrich various national and regional efforts related to earthquake hazard mitigation.

16.2 Regional cooperation is essential as it would reduce the cost and time of developing national expertise in this part of the developing world to address and implement various structural and non-structural measures for seismic hazard mitigation. It is important to note that countries such as Nepal, India and Pakistan have developed specific expertise in different areas of seismic hazard mitigation and those expertise and initiatives can be harnessed for the benefit of the entire region. Most importantly in view of the urgency of the matter due to the fact that an earthquake of higher magnitude can occur any time in Himalaya and Sub-Himalayan region, it is important that some of the issues mentioned below (but not limited to), must be implemented in a phased manner with the mutual cooperation of member countries.

a) **In-depth understanding of the seismic hazard potential** in each country and appreciation of the potential hazard at a place due to an event originating locally or at a far off place. Earthquakes of Kashmir in 2005 and Bhuj in 2001 demonstrate that considerable damages can occur at places as far as 300 km away from the epicenter. Therefore, it is important to know the geophysical characteristics of seismogenic zones across national boundaries. Exchange and sharing of latest seismic hazard maps would help immensely in estimating the damage potential due to a distant earthquake.

b) **Augmentation and densification of seismic observatory** for reducing gap in data collection and analysis. This will particularly help in developing attenuation equations for different parts of the region and better assessment of PGA and ground shaking in the event of an earthquake.

c) **Initiation of joint research for identification of active faults,** surface deformation and strategy for their monitoring across national boundaries. Also develop mechanism to observe possible earthquake precursors based on ground as well as space based observation and share such information among member states.

d) **Development of regional agreement and protocol** so that first responders can come from neighbouring countries at a shortest possible time for SAR activities with equipments including that of helicopters for air lifting etc. Similar protocol should be developed for accessing and deploying medial help (medicine inventory, mobile ambulance, heli – ambulance, blood bank etc.) from across the region as well. Similarly development of protocol for requesting and receiving relief materials such as fast track cargo clearance, import duty exemption etc. from the region in shortest possible time and at a competitive cost shall help to ameliorate the sufferings of the people.

e) **Develop a strategy to move from bilateral to multilateral cooperation** through regional agency in the event of a disaster that would be much more effective in dealing with emergency situation. In tern the regional agency need to be empowered to interact with other regional/ multilateral agencies for receiving help and aid for target member country.

f) **Development of regional framework of sharing information** on a) national initiatives (including building codes, disaster management initiatives, risk transfer model, insurance, generation of scientific data i.e. GPS and geophysical data, development of methodology for assessment of liquefaction hazard, seismicity induced landslides (SIL) and microzonation in operational as well as research domains towards addressing earthquake hazard mitigation measures; b) best practices/examples of structural and non-structural measures and lessons learnt while managing devastating recent earthquakes in the region particularly related to relief, rehabilitation and reconstruction for better management of earthquake effects in future; c) earthquake reconstruction- case histories from South Asia and other parts of the world and development of guidelines for the region so as to incorporate reconstruction and rehabilitation in the developmental planning process.

g) **Analyzing the ongoing international efforts** such as ERRP, UNDP programmes, school safety programmes and retrofitting on other various seismic hazard mitigation measures in different countries and exploring their potential for replication in other countries.

h) **Assessment of capacity building** measures such as opportunities for training and education that exist in each country for generating awareness among the critical masses required for earthquake resistant construction. Exchange of faculty, fellowships, teaching materials etc facilitate cross-fertilization of ideas which are useful for better management of disasters.

i) **Participation in regional as well as national drill/ rehearsal** for Emergency Response to Disaster Management.

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Progress Achieved in the Field of Disaster Management in Pakistan

National Disaster Management Authority, Pakistan

Introduction

Emergency response has remained a predominant approach in Pakistan to deal with disasters until recently. The Calamity Act of 1958, the national policy for disaster management prior to the passing of National Disaster Management Ordinance 2006, was mainly concerned with emergency response. As a result, the country has developed institutional practices and capacities that are predominantly based on emergency response paradigm. Consequently, the establishing of appropriate policy, institutional and legal arrangements to deal with issues of risk and vulnerability was not given priority at higher levels. Therefore, Pakistan lacked such mechanisms and institutions.

Realizing the importance of disaster risk reduction for sustainable social, economic and environmental development, the Government of Pakistan has put in place appropriate legal, policy, and institutional arrangements, and is implementing strategies and programmes to minimize risks and vulnerabilities. In this regard, National Disaster Management Ordinance 2006 has been passed, the implementation of which would be ensured by the National Disaster Management Commission (NDMC) headed by the Prime Minister.

The National Disaster Management Authority (NDMA) has been established as the focal agency for coordinating and facilitating the implementation of strategies and programmes on disaster risk reduction, response and recovery. Similarly, Disaster Management Authorities have been established at provincial/regional and district levels. The NDMA is providing technical guidance to national and provincial stakeholders about formulation of plans, strategies and programmes for disaster risk management. The NDMA is also working on different programmes on capacity development of national, provincial and local stakeholders in collaboration with Provincial Disaster Management Authorities (PDMAs) and District Disaster Management Authorities (DDMAs).

In order to facilitate the integration of DRR into development planning and for capacity development, the NDMA has initiated a number of programs with support from World Bank, UNDP, SIDA, SDC, DFID and other donors. An important program in this regard is the National Capacity Building for Disaster Risk Management (NCBDRM), which is a five year programme covering the whole country. Further, the NDMA is working with the UN system to develop another 2 years Joint Program on Disaster Risk Management.

Disaster Risk Reduction is a National Priority

In synchronization with the Hygo Framework for Action (HFA), the National Disaster Risk Management Framework (NDRMF) has been formulated to guide the work of entire system in the area of disaster risk management. It has been developed through wide consultations with stakeholders at local, provincial and national levels. The Framework envisions, "to achieve sustainable social, economic and environmental development in Pakistan through reducing risks and vulnerabilities, particularly those of the poor and marginalized groups, and by effectively responding to and recovering from disaster impact". Nine priority areas have been identified within this Framework to establish and strengthen policies, institutions and capacities over the next five years: These include:-

i) Institutional and legal arrangements for DRM
ii) Hazard and vulnerability assessment,
iii) Training, education and awareness,
iv) Disaster risk management planning,
v) Community and local level programming,
vi) Multi-hazard early warning system,
vii) Mainstreaming disaster risk reduction into development
viii) Emergency response system, and
ix) Capacity development for post disaster recovery

Legal arrangements have been made under the National Disaster Management Ordinance 2006, for the provision of dedicated resources for disaster management through establishment of National Disaster Management Fund (NDMF). Accordingly, the Federal Government has notified the establishment of NDMF which has received funds from various resources. Besides, the Federal Government has provided substantial funds for the operationalisation of National Disaster Management Authority (NDMA). As envisaged under the National Framework, the NDMA also made arrangements for obtaining commitments for mobilization of resources worth 58 million USD from international donor agencies for implementation of National Policies and Strategies through development programmes in nine priority areas over the next five years.

The local communities, local infrastructures and local economy are directly affected by disasters. At the same time local communities and authorities are first responders to any disaster situation. While appreciating the fore stated facts, Risk Reduction Programme are being implemented at local levels for capacity development of local officials, communities, civil society organizations and other stakeholders.

Utilization of resources and energies at this level generally have lasting impact. NDMA has launched programs in 8 districts, where in collaboration with district governments, local institutions, volunteer networks and capacities are being developed. Additionally, NDMA is working with national and international NGOs to promote community level institutions and volunteerism.

Identify Disaster Risk and Enhance Early Warning.

Institutional commitment has been attained through identifying National Hazard and Vulnerability Assessment as one of the priority areas in the National Disaster Risk Management Framework.

Accordingly, the NDMA has launched the initiative of the National Composite Risk Assessment. The initiative is aimed at carrying out a comprehensive risk analysis and hazard mapping of Pakistan. The digitalized hazards maps will be integrated into the GIS system for accurate and timely decision making in the field of disaster management. The Project is a multi-sectoral exercise, encompassing geological, hydro-meteorological and technological hazards and a major part is expected to be completed by June 2009.

Although, Pakistan has a fairly reasonable system of collecting, archiving and disseminate data on hydro-meteorological hazards through the Pakistan Meteorological Department, WAPDA and Federal Flood Commission but the same needs to be streamlined to ensure timely dissemination of data/information to the communities. However, a national comprehensive system needs to be put in place to monitor, archive and disseminate data encompassing all hazards and supported by a comprehensive compatible IT infrastructure. With the conduct of the National Composite Risk Assessment Exercise in June 2009, Pakistan will have done the first of its kind initiative. It is hoped that the conduct of this national risk assessment exercise would allow Pakistan to develop a system for monitoring of hazards on an ongoing basis.

Local level risk assessment mapping & analysis have been conducted by a number of stakeholders in small cities and districts; e.g. Earthquake Reconstruction and Rehabilitation Authority (ERRA), UNDP, FAO, Pakistan Space and Upper Atmosphere Research Commission (SUPARCO), Agha Khan Planning and Building Service (AKPBS) and OXFAM.

A Seismological survey has been completed by the Pakistan Metrological Department in collaboration with Norway, whereby area wise seismological maps have been developed. The Geological Survey of Pakistan has also conducted seismological survey and developed seismological zoning maps.

With the technical assistance of JICA, a flood risk awareness/management of Lai Nulla Basin in Rawalpindi-Islamabad is being implemented in order to effectively utilize flood EW System already in place.To regulate the Dam reservoir during the monsoon season with a view to avert flood emergency, a Quantitative Precipitation Measurement Radar has been installed in River Jhelum catchments area. In order to fine tune the river flow forecast during monsoon season through Real Time provision of discharges from upstream Areas, Meteorbust Telecommunication System has been installed with 44 remote stations. To fore warn the communities in riverine areas, Flood Plain Maps of Indus River System have been prepared indicating village, important infrastructure and crops etc. Vulnerable to floods.

Negotiations are underway with a number of donors for developing Tsunami Early Warning System, covering the coastal region. NDMA is collaborating with the ADRC and the UNESCAP on a Tsunami Hazard Map Development Project.

Under Clinton Initiative, jointly funded by UNESCO and ISDR, a project on strengthening of Tsunami Warning System is being launched this month.

Use Knoweldge, Innovation and Education to Build a Culture of Safety

NDMA is fully committed to make available information on disaster risks and risk management to all stakeholders. A National Data Center is being established at the NDMA with a range of data and information encompassing all aspects of disasters. The data centre will be connected with National Emergency Operations (NEOC), the Provincial Emergency Operations Centre (PEOC), District Emergency Operations Centres, National and International Research Institutions on Disaster Management to ensure national and trans national flow of information on disasters.

Apart from the above, the NDMA maintains a website where all information related to National DRM Framework, National Disaster Management Ordinance, Training Manuals, Damage and Loss Assessment Reports, Guidelines on preparation of provincial and district level disaster risk management plans and other important documents/information are accessible.

The Government is committed to integrate DRR education in the school, college and university curriculum. The NDMA in close coordination with the Ministry of Education is developing a comprehensive strategy to integrate DRR into education by early 2009. The NDMA is also working on integrating DRR education into the training academies of the civil servants of Pakistan; e.g. the National School of Public Policy (NSPP), the lead civil services training institution where majority of government servants entering into various sectors are trained at the entrance level as well as at mid-career stage. The integration of DRR education into the training modules of NSPP is expected to be completed by end 2009.

To raise awareness and train the civil servants, the NDMA has undertaken different programmes, some of which are mentioned as under:-

- A training program in DRR for in-service government officers at federal, provincial and district levels is under implementation.
- Training curriculum for training of district officials and communities have been prepared.
- Over 150 officers and civil society reps have been trained in the 09 districts affected by the 2005 earthquake. About 80 officials from federal level and from about 40 districts have been trained in basic concepts of DRM.
- A simulation on disaster response management was conducted for the entrance level officers at the Civil Services Academy (CSA) of Pakistan. Training sessions on disaster risk management conducted for about 200 entrance level officers at the CSA.

The National Institute of Disaster Management (NIDM) is being established as the national centre of excellence in the field of Disaster Management. The NIDM will provide state of the art facilities for planning and promoting training and research and developing core competencies in the area of disaster management. It will also be responsible for documentation and development of national level information base relating to disaster management policies, prevention mechanisms and mitigation measures.

Participation of General Public in the ongoing DRR initiatives is crucial to their successful implementation. Accordingly, the NDMA is currently working on a number of initiatives to develop a national awareness raising strategy. 8th October has been declared as the National Disaster Awareness Day by the Government, in commemoration of the October 2005 earthquake, which killed over 73,000 people. NDMA commemorates the 8th October as awareness day with a view to raise awareness of people and stakeholders. NDMA is planning to develop a range of media products for awareness raising, including talk shows, special supplementaries etc.

Realizing the potential of radio as the most effective medium of mass communication, the NDMA is planning to engage FM Channels for raising mass awareness about DRR. For this purpose, a variety of programmes are currently being by the NDMA in collaboration with electronic media. The NDMA also plans to organize orientation sessions for media personnel to engage them in awareness raising activities.

Reduce the Underlying Risk Factors

The National Disaster Management Framework envisages integration of DRR into all sectoral policies and programmes. Institutional commitment has been attained through the National Disaster Management Framework wherein adoption of a risk sensitive approach in development planning and programming in all sectors has been incorporated as a national policy. Under this policy, NDMA in coordination with stakeholders will ensure that all development infrastructure in hazard-prone areas is built to higher standards of hazard resiliency; e.g. schools, hospitals, roads, bridges, dams and telecommunications infrastructure etc. This can ideally be done by incorporating risk and vulnerability assessment into project planning stage, and including vulnerability reduction measures in project implementation in case the proposed projects are found vulnerable to hazard risks.

As a crucial step in the right direction, a National Working Group comprising the NDMA, the Planning Commission of Pakistan, Ministry of Housing and Works, Ministry of Water and Power, Ministry of Industries and Special Initiatives and National Engineering Services Pakistan (Pvt) Limited (NESPAK) has been formed. The Group is working on devising strategies and modalities for the integration of DRR into development policies. It is planned that all future development projects including critical public infrastructure projects will be endorsed by the relevant approving authority only when such projects have the DRR element inherently built in their structural designs.

Likewise, the NDMA is coordinating with the Ministry of Environment to address the underlying risk factors in the implementation of environmental policies. In order to reduce the vulnerability of the impoverished groups on account of food security, a Task Force on Food Security, comprising of all key stakeholders including the NDMA, has been formed in the Planning Commission to address the underlying risk factors in food supply chain.

Pakistan is overly an agrarian economy, with 65 % of its population living in rural areas and dependent on agricultural sources of livelihood. The agricultural sector contributes almost 35 % to the Country's GDP. Therefore, any adverse impact caused by a disaster on agriculture sector may lead to serious repercussions for the national economy as a whole. While appreciating the said fact, the National Framework has assigned the Ministry of Food, Agriculture and Livestock to integrate DRR element in its policies. Accordingly, the Ministry is required to allocate substantial funds for implementation of DRR activities in the hazard prone agricultural areas. The DRR activities ought to focus on vulnerability and risk analysis for food, agriculture and livestock sectors particularly in relation to floods, droughts, cyclones and locust, developing early warning systems, promote contingency crop planning to deal year to year climate variations and crop diversification, ensure sustainable livelihoods in areas of recurrent climate risks by promoting supplementary from off-farm and non-farm activities.

In line with the Framework, the Federal Government has recently announced a comprehensive insurance cover to all crops. Under the crop insurance policy agricultural credits/loans will be offered for insured crops only.

In order to safeguard industrial and productive activities from the impact of disasters, the Framework has assigned responsibility to the Ministry of Industries and Special Initiatives to develop and implement DRR programmes to ensure the continuity of Industrial activities in the event of disasters. The DRR measures to be taken by the Ministry includes developing guidelines for industrial sector to ensure safety of industry and its production processes in hazard-prone areas; incentives and disincentives for industry to promote application of disaster safety measures; Implement awareness raising programmes for industrial sector including Chambers of Commerce and Industry (CCI) on integrating disaster risk assessment and vulnerability reduction in project planning and implementation stages and developing safety codes for all industries to reduce risks of industrial and chemical hazards and to ensure vulnerability reduction from natural hazards;

The NDMA on its part, is developing Guidelines for Industrial and Chemical Contingency Planning which are in the final stage of formulation and will be circulated to all stakeholders for implementation.

In post earthquake (2005) scenario, the thinking is now emerging that Pakistan needs to promote land use planning and implementation of building codes for safer construction. Safer construction practices have been widely followed in the earthquake affected region as part of the reconstruction process. However, promotion and adoption of building codes in other vulnerable parts of the country remains a challenge and a priority agenda for NDMA.

NDMA is working on developing simplified version of the National Building Codes in Urdu language and to disseminate it widely for the benefit of common local masons, contractors, builders and other stakeholders. It believes that the simplified version of building codes would allow people to understand the safer construction requirements and adopt them. NDMA has also launched two small projects to promote safer construction in the cities of Mansehra, Muzafarabad and Quetta.

Disaster risk reduction measures have been integrated into post disaster recovery and rehabilitation processes in the earthquake affected areas. The Earthquake Reconstruction and Rehabilitation Authority (ERRA) is mandated by the Government of Pakistan as the coordinating and implementing agency for reconstruction and rehabilitation of earthquake devastated areas in Pakistan Administered Kashmir (PAK) and NWFP. The overall objective of the rural housing reconstruction policy is to ensure that an estimated 400,000 houses that were destroyed or damaged will be built by using earthquake resistant building techniques through grant assistance from the Government to eligible households. The Reconstruction Framework developed by NDMA with the support of ADB and WB for post 2007 flood reconstruction also includes disaster risk reduction as the key framework for reconstruction and rehabilitation.

Strengthen Disaster Preparedness for Effective Response

The NDMA is currently working on a number of initiatives to develop disaster preparedness capacities. Few key initiatives include the following:-

- Development of the National Disaster Response Plan with Standard Operating Procedures for involvement of all departments and ministries and other stakeholders.
- Establishment/strengthening of the national and provincial Emergency Operations Centers
- Development of a Disaster Information Architecture for post disaster relief and response management
- Contingency planning for key hydro-meteorological hazards; e.g. floods, winter, cyclones in partnership with provincial and local governments
- Preparation of District Disaster Risk Management Plans

In addition to the above, the NDMA is also implementing following two capacity building projects:-

- **Programme for Enhancement of Emergency Response (PEER):**

  PEER is working for capacity development of the Pakistan Army, Rescue 1122 (Punjab Government), Pakistan Red Crescent Society (PRCS) and Ministry of Health in the areas of search and rescue, medical first aid and hospital disaster preparedness. The PEER programme will develop a pool of about 240 national master trainers in the above subjects.

- **Urban Search and Rescue Teams (USARS):**

  Three teams are being established at Karachi, Lahore and Islamabad. These are international standard teams, which will be imparted training at par at international standards and equipped with start of the art Search and Rescue equipment.

The NDMA has developed Monsoon Contingency plan, Winter Contingency Plan for the whole country, and Cyclone Contingency Plan for the City of Karachi and circulated the same for implementation by the relevant stakeholders. As per guidelines provided by the NDMA, the flood prone districts are in the process of preparing their respective contingency plans while some of them have already finalised. The Marine Oil/Chemical Spill Contingency Plan has been finalised and work is on to finalise Industrial Accident Contingency Plan.

The NDMA has provided essential relief items to all the four provinces, Azad Jammu & Kashmir (AJ & K) and Northern Areas (NAs) which have been stockpiled at strategic places to meet future contingencies. These stockpiles are replenished frequently to maintain the local capacities at the desirable level round the year.

In order to effect a synergise response in the event of a disaster, the NDMA coordinates the national response with the involvement of key government departments, UN, donors, NGOs etc. In addition the NDMA organizes regular media briefings to disseminating information on activities/initiatives taken with regard to disaster response. It coordinates with the UN system and NGOs through the system of Inter Agency Standing Committee (IASC) and Disaster Management Team (DMT) and Pakistan Humanitarian Forum. Cluster System under the UN system has been adopted by NDMA as a progressive way of dealing with disasters.

Conclusion

Political will and continuity in policies is key for the successful implementation of National Policies and Strategies on DRR. The major challenge for the development practitioners in the field of DRR would be to secure consistent support from the National Government to treat DRR as a prioritize item on the National Agenda.

The second major challenge is the scarcity of resources for the implementation of short term as well as long term development programmes in the field of DRR, as envisaged under the National Framework. The Government is faced with a crunch situation emanating from regional as well as international politico-economic factors. The unstable economic situation leaves the Government with little fiscal space to spare reasonable funds for DRR programmes. Since the crisis situation is likely to continue for at least next couple of years, the pace of the implementation of DRR policies and strategies as envisaged under the Framework is likely to suffer.

The third major challenge is the lack of capacities on account of trained human resources and modern technology at all levels for planning and subsequent execution of DRR Policies and Programmes. The new disaster management system, envisages developed and decentralized responsibilities for disaster management. However, the Provincial Governments have yet to show the desirable level of commitment, on account of allocation of resources and other administrative measures, to operationalize the institutional arrangements at the Provincial and District levels. The consistent failure of the Provincial Governments to keep pace with the initiatives taken by the NDMA at the Federal level may hamper the implementation of National Policies and Strategies under the Framework, within the desirable time frames.

In line with the HFA commitments, the Government has already put in place legal and institutional arrangements, at the federal, provincial and district levels. The National Disaster Risk Management Framework has been put into force with roles and responsibilities of relevant stakeholders, along with development programmes, in 09 identified priority areas.

The National Composite Risk Assessment exercise is likely to be completed by mid 2009 which will lead to the development of National Hazard Atlas of Pakistan, National Response Plan and establishment of National Emergency Operations Centre (NEOC).

The research/development and training capacities will be enhanced with establishment of National Institute of Disaster Management (NIDM). The Government has already allotted the requisite land in Islamabad and allocated funds for current financial year, for the preparation of project design of the Institute. The Institute will be a Centre of Excellence, catering to the domestic as well as regional training and research needs. If the pace of development work remains in line with the defined timeframes, the institute is expected to be operationalized by 2011.

The National Working Group on Mainstreaming DRR into the Development Policies, is expected to recommend the strategies and modalities for the integration of DR into Development policies and projects within a few months time. It is expected that by 2009, all development policies and programmes, will be designed with DR element inherently built in as a matter of policy.

The capacity building measures taken by the NDMA, to enhance local capacities in preparedness and response, will lead to the establishment of 03 Urban Search and Rescue teams. The training of the USAR teams is currently underway and it is expected that three state of the art teams will become functional very soon, subject to the resolution of administrative bottlenecks being faced by the project at the local levels.

As a key initiative to raise public awareness, the NDMA is coordinating with Ministry of Education to revise the curricula by incorporating DRR in National Syllabi. Likewise, the NDMA is working with the National School of Public Policy (NSPP) for the integration of DRR into the training modules of trainee civil servants. As the result of these initiatives, it is expected that by 2009 a revised curricula integrated with DRR subject will be introduced by 2009..

The on going programmes on developing and updating the Early Warning systems including the establishment of the Tsunami Early Warning System, in collaboration with Pakistan Metrological Department, PMD and WAPDA will lead to enhanced capacities on account of EWSs

Notwithstanding the above likely positive future developments, the analysis of hazard risks, vulnerabilities and dynamic pressures bring home a scenario of more people living in and around hazard-prone areas. New settlements would continue to spring-up with expanding population in hazard prone areas. This trend may worsen over the years since population of Pakistan is expected to be doubled in another 25-30 years. At the other end, the frequency, severity and intensity of certain hazards is on the rise; e.g. droughts, flooding, soil erosion and landslides, resulting from environmental degradation and climate change. From these scenarios it could be concluded that disasters in future would be more frequent and their social, economic and environmental impacts higher than before. Regions that previously were not prone to certain hazards (e.g. droughts, flooding), may experience them in future.

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National Guidelines for Management of Earthquakes

National Disaster Management Authority, India

Background

The Disaster Management Act, 2005 (DM Act, 2005) lays down institutional and coordination mechanisms for effective disaster management (DM) at the national, state, and district levels. As mandated by this Act, the Government of India (GoI) created a multi-tiered institutional system consisting of the National Disaster Management Authority (NDMA), headed by the Prime Minister, the State Disaster Management Authorities (SDMAs) by the Chief Ministers and the District Disaster Management Authorities (DDMAs) by the District Collectors and co-chaired by elected representatives of the local authorities of the respective districts. These bodies have been set up to facilitate the paradigm shift from the hitherto relief-centric approach to a more proactive, holistic and integrated approach of strengthening disaster preparedness, mitigation and emergency response.

Soon after the NDMA was set up, a series of consultations were initiated with various stakeholders to facilitate the development of guidelines for strengthening earthquake management. Senior representatives from government departments and agencies, academics, professionals, multilateral and humanitarian agencies and corporate sector representatives participated in these meetings. These meetings acknowledged that several initiatives taken up by government agencies in the recent past have been significant and far-reaching, but they also highlighted the need for a holistic and integrated strategy. On the basis of these deliberations, the NDMA has prepared these Guidelines for the Management of Earthquakes, (hereinafter referred to as the Guidelines), to assist the ministries and departments of the GoI, state governments and other agencies to prepare DM plans.

Earthquake Risk in India

India's high earthquake risk and vulnerability is evident from the fact that about 59 per cent of India's land area could face moderate to severe earthquakes. During the period 1990 to 2006, more than 23,000 lives were lost due to 6 major earthquakes in India, which also caused enormous damage to property and public infrastructure. The occurrence of several devastating earthquakes in areas hitherto considered safe from earthquakes indicates that the built environment in the country is extremely fragile and our ability to prepare ourselves and effectively respond to earthquakes is inadequate. During the International Decade for Natural Disaster Reduction (IDNDR) observed by the United Nations (UN) in the 1990s, India witnessed several earthquakes like the Uttarkashi earthquake of 1991, the Latur earthquake of 1993, the Jabalpur earthquake of 1997, and the Chamoli earthquake of 1999. These were followed by the Bhuj earthquake of 26 January 2001 and the Jammu & Kashmir earthquake of 8 October 2005.

All these major earthquakes established that the casualties were caused primarily due to the collapse of buildings. However, similar high intensity earthquakes in the United States, Japan, etc., do not lead to such enormous loss of lives, as the structures in these countries are built with structural mitigation measures and earthquake-resistant features. This emphasises the need for strict compliance of town planning bye-laws and earthquake-resistant building codes in India. These Guidelines have been prepared, taking into account an analysis of the critical gaps responsible for accentuating the seismic risk and of factors that would contribute towards seismic risk reduction, to enable various stakeholder agencies to address the critical areas for improving seismic safety in India.

Overview

Long-term and sustained efforts are required to address the problem of earthquake risk in India. These Guidelines have been prepared to reduce the impact of earthquakes in the short term and the earthquake risk in the medium and long term. They recognise the enormous challenge in improving seismic safety because of the inadequate numbers of trained and qualified civil engineers, structural engineers, architects and masons proficient in earthquake-resistant design and construction of structures. They also acknowledge the need for imparting training in earthquake-resistant design and construction to faculty members in professional colleges, for revising the curriculum in professional courses, and for creating public awareness on seismic risk reduction features in non-engineered construction in earthquake-prone areas.

Guidelines for the Preparation of DM Plans

The National Executive Committee (NEC) will prepare the National Disaster Management Plan which will be approved by the NDMA. The Ministry of Earth Sciences (MoES), as the nodal ministry will prepare the Earthquake Management Plan covering all aspects like earthquake preparedness, mitigation, public awareness, capacity building, training, education, Research and Development (R&D), documentation, earthquake response, rehabilitation and recovery. The Indian Meteorological Department (IMD) will be the nodal agency forthe monitoring of seismic activity while the Bureau of Indian Standards (BIS) will be the nodal agency for preparing earthquake-resistant building codes and other safety codes. All such key stakeholders, including central ministries and departments and state governments/SDMAs will develop detailed DM plans, recognising the seismic risk in their respective jurisdictions, based on these Guidelines. Similarly, the SDMAs will lay down appropriate Guidelines for the preparation of DM plans by Urban Local Bodies (ULBs), Panchayati Raj Institutions (PRIs) and district administration, keeping in view the seismic risk considerations in their respective areas. These Guidelines are drawn up in the context of a rigorous Risk Management (RM) framework to ensure the effectiveness of DM plans that are developed by various agencies. Communities and other stakeholders will ensure compliance to the town planning bye-laws, earthquake-resistant building codes and other safety regulations, as well as their effective enforcement. The state governments/SDMAs will be responsible for reviewing and monitoring the implementation of the DM plans.

Structure of the Guidelines

These Guidelines consist of three broad sections: *(a)* the context and approach to the management of earthquakes in India; *(b)* an outline of the specific Guidelines; and *(c)* a broad overview of the DM plans to be prepared by the central ministries and departments, state governments, other stakeholders and nodal agencies.

(a) The first section covers the following:

- an overview of the earthquake risk and vulnerability in India;
- a brief review of the status of earthquake management efforts;
- an overview of the recent initiatives of the government for ensuring earthquake risk reduction;
- an identification of the critical areas which require special attention to ensure that the overall strategy for the management of earthquakes in India is holistic, integrated and supportive to the development aspirations of building a modern nation;
- an outline of a rational RM framework to institutionalise systems and processes to make earthquake safety in India asustainable strategy;
- an introduction to the six pillars of earthquake management, with prescribed time lines for the effective implementation of the various activities; and
- an overview of the issues which need to be addressed to ensure the effective implementation of the plans formulated based on these Guidelines.

(b) The second section outlines each of the six pillars for effective earthquake management in India.

(c) The third section provides an overview of the DM plans to be prepared by the central ministries and departments, state governments, other stakeholders and nodal agencies.

Special attention needs to be given to ensure the earthquake safety of non-engineered construction in rural areas, as more than 61 per cent of the buildings in rural areas are built with mud and clay, stone, brick and/or concrete, compared to 26.7 per cent of similar buildings in urban areas. The large number of fatalities due to earthquakes in rural areas during the period 1990 to 2006 also makes it imperative to pay special attention to the earthquake safety of buildings being constructed in these areas.

The Six Pillars of Earthquake Management

These Guidelines envisage the institutionalisation of stakeholder initiatives, by involving communities and other key stakeholders. covering pre-disaster components of mitigation and preparedness based on scientific and technical principles, as well as on indigenous technical knowledge and building techniques.They simultaneously address the incorporation of multi-hazard resistant features in the reconstruction of damaged buildings and outline the strategy for strengthening the post-disaster components of emergency response, rehabilitation and recovery.

Even though earthquake-resistant building codes and town planning bye-laws and regulations exist, these are not strictly enforced.

Given the high seismic risk and earthquake vulnerability in India, these Guidelines require all stakeholders to ensure that, hereafter, all new structures are built in compliance of earthquake-resistant building codes and town planning bye-laws. This will be taken up as a national resolve. This is in recognition of the seriousness of the high seismic risk in India and the increasing trends of urbanisation and modernisation that demand the construction of flyovers, multi-storied buildings, super malls, techno parks, etc., in metropolitan cities thereby multiplying the risks manifold. The fragile built environment in India, especially in moderate and high seismic risk zones, is a matter of serious concern. It is neither practical nor financially viable to implement strengthening and retrofitting of all existing structures in moderate and high seismic risk zones in India.

These Guidelines emphasise the need for carrying out the structural safety audit of existing lifeline structures and other critical structures in earthquake-prone areas, and carrying out selective seismic strengthening and retrofitting.

Apart from these two sets of initiatives which are aimed at improving the seismic safety of the built environment, these Guidelines also emphasise the need for strengthening enforcement andr egulation, awareness and preparedness, capacity development (including education, training, R&D, and documentation) and earthquake response.

As mentioned earlier, these Guidelines have been prepared through a series of consultations with key stakeholder groups in New Delhi, Kanpur and Mumbai. These consultations identified the critical factors responsible for the high seismic risk in India and prioritised six sets of critical interventions, which have been presented in these Guidelines as the six pillars of earthquake management. They will help to:

1. Ensure the incorporation of earthquake-resistant design features for the construction of new structures.
2. Facilitate selective strengthening and seismic retrofitting of existing priority and lifeline structures in earthquake-prone areas.
3. Improve the compliance regime through appropriate regulation and enforcement.
4. Improve the awareness and preparedness of all stakeholders.
5. Introduce appropriate capacity development interventions for effective earthquake management (including education, training, R&D, and documentation).
6. Strengthen the emergency response capability in earthquake-prone areas.

Milestones for Implementing the Guidelines

These Guidelines envisage two phases for ensuring seismic safety. During Phase I, which is scheduled to commence with immediate effect and conclude by 31 December 2008, the various stakeholders will prepare their DM plans and carry out specific activities aimed at seismic risk reduction. These activities are the most challenging ones, as the stakeholders not only clearly articulate the earthquake safety issues during this phase, but also put in place institutions and processes for moving towards systematic seismic risk reduction. The activities to be carried out during Phase I include the following:

- Preparing DM plans; revising town planning bye-laws and adopting model bye-laws; disseminating earthquake-resistant building codes, the National Building Code 2005 and other safety codes.
- Training trainers in professional and technical institutions; training professionals like engineers, architects, and masons in earthquake-resistant construction.
- Launchin g demonstration projects and public awareness campaigns to dis seminate earthquake-resistant techniques, seismic safety and seismic risk reduction.
- Enforcing and tablishing an appropriate mechanism for compliance review of all construction designs submitted to ULBs; undertaking mandatory technical audit of structural designs of major projects by the respective competent authorities.
- Developing an inventory of the existing built environment; assessing its seismic risk and vulnerability by carrying out a structural safety audit of all critical lifeline structures.
- Developing and undertaking seismic strengthening and retrofitting standards for existing critical lifeline structures, initially as pilot projects and for other critical lifeline structures in a phased manner.
- Increasing the awareness of earthquake risk and vulnerability and seismic risk reduction measures to various stakeholders through sensitisation workshops, seminars and public awareness campaigns.

Preparing DM plans by schools, hospitals, super malls, entertainment multiplexes, etc. and carrying out mock drills for creating greater public awareness.

Strengthening the Emergency Operations Centre (EOC) network.

Streamlining the mobilisation of communities, civil society partners, the corporate sector and other stakeholders.

Preparing national, state and district DM plans, with specific reference to the management of earthquakes.

Preparing community and village level DM plans, with specific reference to management of earthquakes.

Carrying out the vulnerability mapping of earthquake-prone areas and creating inventory of resources for effective response.

Carrying out earthquake safety education in educational institutions and conducting mock drills.

Strengthening earthquake safety R&D in professional technical institutions.

Preparing documentation on lessons from previous earthquakes and ensuring their wide dissemination.

Developing an appropriate mechanism for licensing and certification of professionals in earthquake-resistant construction techniques by collaborating with professional bodies.

- Developing appropriate risk transfer instruments by collaborating with insurance companies and financial institutions.
- Setting up National Disaster Response Force (NDRF) battalions, training and equipping them.
- Setting up State Disaster Response Force (SDRF) battalions in high seismic risk states, training and equipping them.
- Strengthening the medical preparedness for effective earthquake response.

These activities will be initiated by the central ministries and departments and state governments, other key stakeholders and nodal agencies concerned as parallel processes. A review of the DM plans and activities carried out during Phase I will be undertaken, from January to June 2009. Thereafter, the plans will be revised and updated, with special emphasis on areas that need greater attention to achieve the objective of institutionalising seismic risk reduction. The activities of Phase I will continue during this period and be further intensified in Phase II. The implementation of Phase II will commence from 1 January 2010.

Table 1: Important Milestones for the Implementation of the Guidelines

S. No.	Items	Commencement	Action and Date of Completion
Phase I Implementation of the Guidelines			
1	Development of detailed action plans for each Phase I activity	With immediate effect	With immediate effect
2	All activities of Phase I	With immediate effect	With immediate effect
3	Mid-term monitoring and correction of implementation plans of all Phase I activities	With immediate effect	With immediate effect
4	Completion of Phase I activities	With immediate effect	With immediate effect
5	Major review of all action plans of all activities of Phase I	With effect from 1 January 2009	With effect from 1 January 2009
Phase I Implementation of the Guidelines			
6	Identification of activities to be undertaken in Phase II, and development of detailed action plans for the same	Initiate by 1 July 2009	Complete by 31 December 2009
7	Implementation of all Phase II activities		Underway by 1 January 2010

Preparing for the Big One in Kathmandu Valley

National Society of Earthquake Technology, Nepal

In the past, large earthquakes in Nepal have caused huge numbers of casualties and extensive damage to structures. The Great Nepal-Bihar earthquake in 1934 reportedly killed 8,519 people and damaged over 80,000 buildings in Nepal. Later, the 1988 Udayapur Earthquake also resulted in heavy loss of life in the eastern region and also in the Kathmandu valley. Sadly the earthquake risk in Nepalese cities, and especially in the Kathmandu Valley, is still increasing owing to rapid urbanization with uncontrolled development and poor construction practices. Despite the knowledge of historical seismicity, and continued geological research in the Nepal Himalayas, public awareness of earthquake hazard and risk was minimal until a few decades ago, and implementation of earthquake risk management efforts was almost nonexistent. The 1988 Udayapur Earthquake was a major turning point. Following the massive destruction and the death toll of 721 lives the need for an organized approach was felt in all quarters. Since then, several initiatives were conceptualized and implemented by governmental as well as non-governmental sectors to minimize the risk of earthquakes. The initiatives implemented by the National Society for Earthquake Technology – Nepal (NSET) have been very effective, particularly due to their contribution toward raising the earthquake awareness of the general population as well as the awareness of the authorities. The following text aims to highlight some of the effective programs and activities of NSET. School Earthquake Safety Program (SESP) Public schools in Nepal, both the buildings and their occupants, face extreme risk from earthquakes. While they face this risk schools also play a crucial role after an earthquake in helping a community to get back on its feet. So by raising awareness in schools, the entire community is reached because the lessons trickle down to parents, relatives, and friends of pupils and teachers. Realizing this fact, NSET has been implementing community based School Earthquake Safety Program (SESP) since 1999. As a first step toward working in schools, NSET carried out a Kathmandu Valley-wide vulnerability assessment survey of about 1100 buildings in 643 public schools. The findings were alarming; more than 60% of the buildings were found to be highly vulnerable even in normal conditions. This alarming finding urged NSET to implement vulnerability reduction programs in schools, which led to a pilot program for retrofitting one of the public schools in a rural area of Kathmandu Valley in 1999. Since then SESP has been implemented in more than 20 schools in different parts of the country. Primary objectives of the program are to identify measures to reduce earthquake risk, to raise awareness of risk while implementing the program and to train local masons in earthquake-resistant construction. Accordingly, SESP consists of the following components: (a) seismic retrofitting or earthquake-resistant reconstruction of schools buildings; (b) training of teachers, students and parents in earthquake risk mitigation and preparedness; (c) training of local masons in earthquake-resistant building construction technology. The program has been found to be successful in instigating community participation in all components of program activities and in the ability to raise the earthquake awareness of communities significantly. The masons trained during the program are now acting as ambassadors to spread the technology of earthquake-resistant construction in their communities and replicating the technology in the construction of new buildings; they are also training other masons. The program has also clearly demonstrated that community-based activities for disaster risk reduction are effective and sustainable. Once the process is started it will continue to be effective in ever-increasing areas. The rich experience gained during the implementation of this program has been translated into a technical manual for designers and builders to assist them in designing and implementing earthquake-resistant school-building construction. Further, the approach and methodology of this program is in the process of adoption by the Ministry of Education and other educational institutions in their regular plans and programs.

Seismic Vulnerability Assessment of Nepalese Hospitals   As a joint effort with the Ministry of Health of His Majesty's Government of Nepal and WHO Nepal, NSET conducted two studies: "Structural Assessment of Hospitals and Health Institutions of Kathmandu Valley" and "Non-Structural Vulnerability Assessment of Hospitals in Nepal" in 2001 and 2003. A systematic approach to the seismic assessment of hospitals in Nepal was developed while carrying out those assessments on major Nepalese hospitals. The necessity of developing such a methodology arose because methodologies from developed countries could not be applied to Nepal. The results of the studies show that about 80% of the hospitals assessed in the study fall in the unacceptable performance category for new construction and the remaining 20% of hospitals are at high risk of life-threatening collapse.. Recommendations were made to improve the seismic performance of different hospitals on a priority basis . The securing of all equipment and contents, strengthening of critical systems, training for hospital personnel and provision of some backup for critical systems were proposed for implementation in the first phase. Seismic retrofitting of hospital buildings, further strengthening of critical systems and provision of extra backup systems were the proposed activities for second-phase implementation. Considering the opportunity of immediate implementation of non-structural risk mitigation, some examples of mitigation options to solve the problems were developed during the study.

As a follow-up action, NSET and WHO Nepal conducted a series of meetings with government authorities and donor agencies to identify possible courses of action and the possible resources involved. There are many positive signs for implementing non-structural mitigation measures in selected hospitals within the Kathmandu Valley. Seismic Vulnerability Assessment of the Drinking Water Supply System in Kathmandu Valley NSET undertook a study to assess the seismic vulnerability of the drinking water supply system of Kathmandu City with support from UNICEF Nepal in 2002 in view of the high level of earthquake risk. A practical methodology for assessing the seismic vulnerability of the water supply network, its components and institutional capacity was developed. Assessment results in the form of network system damage scenarios for earthquakes were presented using a Geographical Information System (GIS). Based on possible maximum enhancement of present institutional capacity and spatial distribution of the possible extent of damage, optimum routes for the most expedient restoration of the water supply services to meet a minimum level are identified under two different scenarios, as is and an improved system. Spatial distribution of emergency water demand in case of an earthquake was also offered as one of the recommendations of the study.

Initiative to set up Pre-Positioned Emergency Rescue Stores (PPERS) This initiative was jointly carried out by NSET and different ward disaster-management committees of Kathmandu Valley and was supported by the Civil Affairs Group of the British Army. The purpose of PPERS is to provide a reserve of essential tools and equipment to assist in the immediate response to a major disaster, such as an earthquake, in the Kathmandu Valley. PPERS are intended to help those 'first responders' on the ground at the local level to enable neighbors to rescue neighbors. Organizational structures such as local-level disaster-management committees and community emergency-response teams are constituted as required to assist in setting up the stores and their effective operation. Seventy-three items helpful during emergencies are included in the stores and 223 volunteers can work together at one time using this equipment for emergency rescue work. Such stores are pre-positioned in eight locations within Kathmandu Valley. Kathmandu Valley Earthquake Preparedness Initiative (KVEPI) According to a study carried out during the Kathmandu Valley Earthquake Risk Management Project (KVERMP) by NSET, a major earthquake in Kathmandu Valley today would cause over 40,000 deaths, over 95,000 injuries, leave over 700,000 homeless, damage 60% of the building stock beyond repair, and severely damage the road network including countless bridges as well as the public water-supply system. To combat such events, a program called Kathmandu Valley Earthquake Preparedness Initiative (KVEPI) is being implemented in ten locations in the Kathmandu Valley as a joint program of NSET, the Nepal Red Cross Society (NRCS) and the American Red Cross. This program uses a combined approach of building the capacity and volunteer base of the NRCS, pre-positioning critical relief supplies and rescue equipment, drilling water points, training people in basic first aid and rescue techniques and helping the general public to identify and advocate for safer building practices. Thus the primary goal of the initiative is to improve the resilience of communities and to reduce suffering from earthquake disasters.

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Seismic Hazard and Risk Assessment in Afghanistan

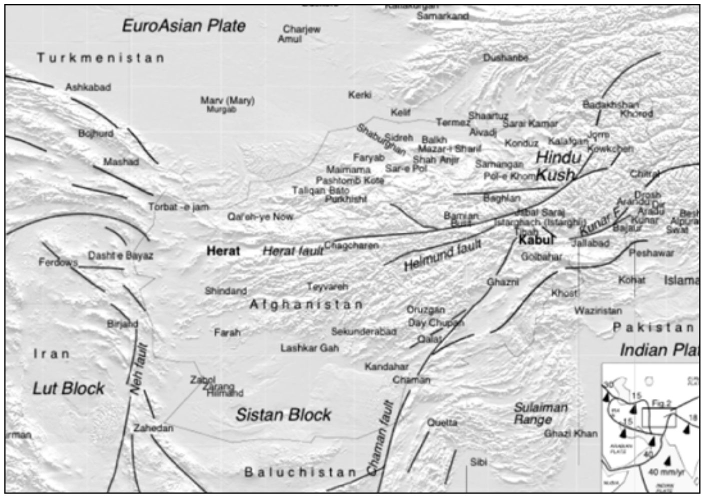
Seismic Hazard Assessment

Earthquakes represent a serious threat to the people and institutions of Afghanistan. In order to assess the potential seismic hazards of Afghanistan, the Seismic Hazard Mapping group of the United States Geological Survey (USGS) has prepared a series of probabilistic seismic hazard maps that help quantify the expected frequency and strength of ground shaking nationwide. Seismic hazard assessment in Afghanistan is challenging because the geological and seismological data required to produce a seismic hazard model are limited. The data that are available include historical seismicity and poorly constrained slip rates on only a few of the many active faults in the country: the Chaman fault with an assigned slip rate of 10 mm/yr, the Central Badakhshan fault with an assigned slip rate of 12 mm/yr, the Darvaz fault with an assigned slip rate of 7 mm/yr, and the Hari Rud fault with an assigned slip rate of 2 mm/yr. Within these limitations, USGS developed a preliminary probabilistic seismic-hazard assessment of Afghanistan, the type of analysis that underpins the seismic components of modern building codes in the United States. The assessment includes maps of estimated peak ground-acceleration (PGA), 0.2-second spectral acceleration (SA), and 1.0-second SA, with return periods of about 500 years (equal to a 10-percent probability in 50 years) and 2,500 years (equal to a 2-percent probability in 50 years).

According to this assessment, eastern and northeastern parts of the Afghanistan is very high hazard prone due to presence of faults and past seismic history. Kabul has been estimated to have the highest seismic hazard due its proximity with the active Chaman Fault and in the past it has been devastated by earthquake. The western Afghanistan has low seismic hazard as compared to the east. However, Herat, on the western part of the country, has relatively higher hazard due to its proximity to Hari Rud fault.

Seismotectonics of Afghanistan

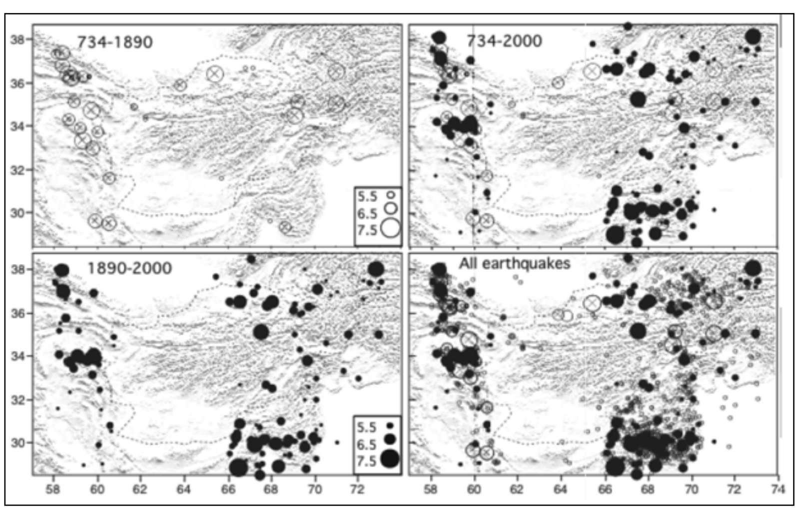
Afghanistan occupies a southward-projecting, relatively stable promontory of the Eurasian tectonic plate. Active plate boundaries, however, surround Afghanistan on the west, south, and east. To the west, the Arabian plate moves northward relative to Eurasia at about 3 cm/yr. The active plate boundary trends northwestward through the Zagros region of southwestern Iran. Deformation is accommodated throughout the territory of Iran; major structures include several north-south-trending, right-lateral strike-slip fault systems in the east and, farther to the north, a series of east-west-trending reverse- and strike-slip faults. This deformation apparently does not cross the border into relatively stable western Afghanistan. In the east, the Indian plate moves northward relative to Eurasia at a rate of about 4 cm/yr. A broad, transpressional plate-boundary zone extends into eastern Afghanistan, trending southwestward from the Hindu Kush in northeast Afghanistan, through Kabul, and along the Afghanistan-Pakistan border. Deformation here is expressed as a belt of major, north-northeast-trending, left-lateral strike-slip faults and abundant seismicity. The seismicity intensifies farther to the northeast and includes a prominent zone of deep earthquakes associated with northward subduction of the Indian plate beneath Eurasia that extends beneath the Hindu Kush and Pamirs Mountains.



Tectonic Map of Afghanistan
(Source: Earthquakes in Afghanistan, N. Ambraseys and R. Bilham)

Seismicity in Afghanistan

The distribution of earthquake epicenters in Afghanistan reveals that the northern and eastern parts of the country are more vulnerable compared to the southern Afghanistan that lies on the un-deformed Eurasian plate. The catalogue of more than 12,000 earthquakes compiled by USGS indicates that the shallow focus earthquakes are concentrated along eastern part of Afghanistan whereas northeastern Afghanistan is marked by shallow as well as deep focus earthquakes. Plot of historical earthquakes by researchers also show similar trend



(Source: Earthquakes in Afghanistan, N. Ambraseys and R. Bilham)

Recent Important Earthquakes in Afghanistan (Source: USGS)

- 1965 03 14 - Hindu Kush, Afghanistan - M 7.8
- 1998 02 04 - Afghanistan-Tajikistan Border Region - M 5.9 Fatalities 2,323
- 1998 05 30 - Afghanistan-Tajikistan Border Region - M 6.6 Fatalities 4,000
- 2002 03 03 - Hindu Kush Region, Afghanistan - M 7.4 Fatalities 166
- 2002 03 25 - Hindu Kush Region, Afghanistan - M 6.1 Fatalities 1,000
- 2004 04 05 - Hindu Kush Region, Afghanistan - M 6.6 Fatalities 3
- 2005 12 12 - Hindu Kush Region, Afghanistan - M 6.5 Fatalities 5

Seismic Risk Assessment and Management

As per the above mentioned seismic hazard map, seismic events and geographical distribution of provinces in Afghanistan, the following hazard and risk status has been identified along with other hazards. Based on this a Comprehensive Disaster Risk Reduction Programme (CDRRP) has been launched by UNDP in collaboration with Afghanistan National Disaster Management Authority to address some of the issues related to seismic hazard mitigation under capacity building and response mechanism.

Table 1: Natural Hazards Occurrences by Provinces (estimated)

No	Province	Population	Earthquake	Drought	Flood	Landslide	Avalanche
1	Kabul	2,974,808	M	L	L	L	M
2.	Kapisa	360,292	M	M	L	L	H
3	Parwan	762,839	M	M	L	L	H
4	Logar	291,880	M	M	L	M	M
5	Wardak	413,596	L	M	M	L	H
6	Bamian	340,005	M	H	M	L	H
7	Ghazni	1,865,762	L	M	H	L	H
8	Ghor	486,108	L	H	H	L	L
9	Paktika	352,629	L	M	M	L	L
10	Khost	70,246	L	H	M	L	L
11	Nuristan	111,898	L	L	L	L	M
12	Laghman	308,260	M	M	M	L	M
13	Ningarhar	1,086,593	M	M	M	L	L
14	Kunar	321,662	M	M	M	L	M
15	Badakhshan	593,148	H	M	H	H	H
16	Baghlan	758,242	H	M	M	H	H
17	Kunduz	815,107	M	M	H	M	M
18	Takhar	697,601	H	M	M	H	M
19	Balkhm	935,742	M	H	H	M	M
20	Faryab	699,897	M	H	H	L	M
21	Jawzjan	508,660	M	H	H	L	M
22	Zamangan	304,073	H	M	H	H	M
23	Sar-I-Pul	467,763	M	H	M	L	L
24	Helmand	745,616	M	H	M	L	M
25	Kandahar	826,870	L	H	M	L	L
26	Nimroz	149,339	L	H	M	L	L
27	Uruzgan	639,115	L	H	H	L	H
28	Zabul	282,170	L	H	M	L	H
29	Badghis	758,242	L	H	M	L	M
30	Farah	338,276	M	H	M	L	M

H : High M: Medium L: Low

Thimphu Valley earthquake Risk Management Project

Standards and Quality Control Authority, Bhutan

Background

Bhutan lies in one of the most seismically active zones of the world. Records suggest that while four great earthquakes of magnitude exceeding 8 on the Richter scale occurred during 1897, 1905, 1934 and 1950, another 10 earthquakes exceeding magnitude 7.5 have occurred in the Himalayan belt during the past 100 years. However, a detailed seismic micro-zonation of Bhutan, which could reveal the multiplicity of risks facing different parts of the country, is currently not available. With one of the highest densities of population and correspondingly rapid rates of development in the country, Thimphu valley is the nerve centre of Bhutan. This feature makes it the 'hotspot' both as a high-risk earthquake site and as the lead disaster response site (due to the concentration of capacities) for any earthquake in its vicinity. Further, there is limited technical capacity in Bhutan to structurally analyze the seismic safety of old buildings.

In recognizing these existing gaps, the Royal command, conveyed to the Minister of Works & Human Settlement and the subsequent instruction by the Hon'ble Minister in April 2004, the Standards and Quality Control Authority initiated the "Thimphu Valley Earthquake Risk Management Project" (TVERMP) with support from the UNDP with an approved budget outlay of US$ 66,150.00 (US Dollars sixty six thousand one hundred fifty only).

Project Objectives and Expected Outputs

S. No.	Activity	Output
1	Development of earthquake damage scenario for Thimphu Valley using the RADIUS Methodology and develop an earthquake risk management action plan with short, medium and long term recommendations.	Earthquake damage scenarios (loss of lives, injury and damages to infrastructure) for various hypothetical earthquakes have been developed for Thimphu Valley using RADIUS tool. Thimphu Valley Earthquake Risk Management Action plan has been developed with broad consultation of the stake holders during the "Sensitization Workshop and Building Partnership for Earthquake Risk Management" which was jointly organised by SQCA and UNDP on 19th August 2005 Findings of the RADIUS damage assessment has been shared during the "TVERMP Dissemination workshop" which was held on 14th December 2005.
2	Vulnerability assessment of 15 buildings in Thimphu Valley	Detailed seismic vulnerability assessment of 15 buildings has been completed in technical assistance from Nepal based international consultancy firm John Sanday Associates. Individual buildings have been evaluated for seismic safety and two retrofitting options have been suggested to strengthen the buildings.

S. No.	Activity	Output
		The results of the detailed analysis of the 15 buildings were discussed by JSA team with the house owners along with the SQCA engineers on 13th December 2005.
3	Document methodology and tools for Rapid Visual Assessment of some of the most prevalent building types in Thimphu	Rapid Visual Screening for seismic safety has been carried out for the buildings in the Thimphu Valley. Various damage grades have been assigned to individual buildings that were surveyed. According to the study large numbers of buildings need to undergo detailed vulnerability assessment. Details of the survey information have been documented through Building Information System which was developed under the project.
4	Build technical and human capacity for earthquake vulnerability assessment and earthquake resistant construction	Engineers from SQCA have been trained in carrying out vulnerability assessment of buildings by the consultant and the UNV on RADIUS Tool and Rapid Visual Screening of Buildings. Four national engineers visited the office of JSA in Katmandu, Nepal, to familiarise themselves with seismic assessment of buildings from 15th - 25th May 2005. Two engineers were sent for a training programme on Aseismic Design and construction at International Institute of Earthquake Engineering and Engineering Seismology, Skopje, Macedonia. One was fully sponsored by the Institute and the other was supported by UNDP.
5	Produce awareness material on the project and earthquake resistant construction technology and good practices	IEC materials such as flyers and posters on Do's and Don'ts and safe construction practices have been developed by SQCA and was also displayed and distributed during the Construction Expo 2005.
6	Disseminating output related to the process and product of the project to strategic stakeholders at different points during the project	A "Sensitization Workshop and Building partnership for earthquake risk management" was organized on 19th August 2005. The aim of the workshop was to share the regional experiences on earthquake risk reduction and the applicability of their best practices in TVERMP. Thimphu Valley Earthquake Risk Management Action plan was developed in broad consultation with the stake holders. (Copy of the workshop report has been enclosed) A meeting was organised on 13th October 2005 with the house owners of the 15 buildings, wherein JSA team made a detailed presentation of the individual buildings. "TVERMP Dissemination workshop" was held on 14th December to present the findings of the study conducted under the project to the stakeholders. (Copy of the workshop report has been enclosed)

Progress Acheived:

All the objectives outlined in the Project have been achieved.

1. The development of the earthquake scenario using the RADIUS methodology was carried out successfully with the guidance from Mr. M. Jaiganesh, UNV Technical Officer.
2. The vulnerability assessment of 15 residential type buildings in the Thimphu Valley, was out sourced to John Sanday Associates Pvt. Ltd. (JSA), an international consultancy firm based in Katmandu, Nepal. The Final Report was presented to the various stakeholders by JSA on 13th & 14th December 2005.
3. The Rapid Visual Assessment of various buildings have been carried out using the Rapid Visual Screening (RVS) method from the information collected for the RADIUS methodology. Various damage grades have been assigned to individual buildings that were surveyed.
4. The national engineers have been trained in the use of the RADIUS software and the RVS method. Four national engineers visited the office of JSA in Kathmandu, Nepal, to familiarise themselves with seismic assessment of buildings from 15th - 25l May 2005. Two engineers were sent for a training programme on A seismic Design and construction at International Institute of Earthquake Engineering and Engineering Seismology, Skopje, Macedonia. One was fully sponsored by the Institute and the other was supported by UNDP.
5. Awareness materials have been prepared and distributed.
6. Two workshops were conducted to disseminate information on TVERMP in particular and earthquakes in general.

Constraints:

The following are some of the constraints faced during the project:

1. The selection of the 15 buildings for the vulnerability assessment was carried out based on some criteria that took into account its age, physical condition, etc. However, the owners were reluctant to participate in the study and therefore, some buildings later bad to be substituted which hampered the progress of the study.
2. For RADIUS we employed over 60 temporary staff to collect information of the building stock in the Thimphu Valley. More than 5000 buildings were surveyed. During the course of the data collection the temporary staffs were sometimes not allowed to enter the premises and at times were subjected to verbal abuses.

Recommendations

Awareness Generation and Public Education

Formulate earthquake risk awareness programs in the valley by a series of activities targeting all the stakeholders. These stakeholders include the various ministries and departments, vulnerable communities, and people working in construction industry Develop and disseminate Information, Education and Communications (IEC) materials on simple and cost effective earthquake resistant technologies on safe construction and retrofitting practices.

Develop and disseminate information and communication materials on 'Do's and Don'ts' for earthquake safety Construct Technology Demonstration Unit (TDU) for disseminating cost effective disaster resistant technologies

Preparedness for Effective Emergency Response

Develop a comprehensive City Disaster Management Plan and Standard Operations Procedure for the departments involved in emergency response

- Initiate local level risk management activities by involving vulnerable communities
- Undertake a study to map the collateral hazards such as landslide, liquefaction prone areas.
- Identify gaps in the existing response mechanism and improve its response
- Develop inventory of resources which will be critical for emergency response
- Develop sectoral emergency preparedness and response plans (health sector, water and sanitation, infrastructure etc.
- Improve the communications and transportation networks
- Strengthen the seismic performance of existing critical infrastructures such as hospitals, schools, bridges and emergency services
- Establish emergency operation center (EOC) for emergency coordination as well as a public information.
- Train local volunteers in basic search and rescue operations, first aid etc
- Organize periodic mock drills to test and improve the preparedness for emergency response

Techno-legal regime

- Study existing codal provisions for possible revision
- Adopt and enforce latest building codes
- Prepare / update land use plans for the valley with latest available information
- Integrating disaster risk reduction activities in the ongoing and future development projects and plans
- Allocate funds to undertake mitigation activities

School Earthquake Safety Programme

Formulate a school safety programme for the valley that focuses on:

- Preparing School Disaster Management Plans
- Training and rehearsing on evacuation plans
- Identifying vulnerable schools and develop retrofitting priorities or to relocate unsafe buildings
- Incorporating disaster risk management plans in school curriculum
- Developing a pool of school students who can volunteer in basic first aid and rescue operation
- Promoting higher standards of safety in the construction of new school buildings

Strengthening/ upgrading critical facilities

- Protect and strengthen critical infrastructure, in order to ensure that emergency response activities can be carried out as smoothly as possible

Conduct detailed vulnerability assessment of lifeline systems such as

- Water supply and drainage
- Electric substations
- Telecommunications and Communications towers
- Bridges
- Fire services
- Airport
- Prepare time-bound action plans to strengthen the above to certain minimum safety standards

Training and Capacity Building

- Undertake studies on vulnerability assessment of most prevalent buildings and develop retrofitting strategies
- Provide training of professionals in conducting vulnerability assessments and retrofitting strategies
- Stren•gthening the emergency response services to undertake search and rescue capabilities.
- Training of local volunteers in basic search and rescue, first aid
- Establish network of seismological station and upgrade existing station to monitor seismic activity in the region
- Include modules on earthquake engineering design in Diploma and Engineering curriculum

Establish network with other programme /cities

Establishing linkages with the proposed Integrated Disaster Risk Management programme (IDRM)

Establish networks with the other cities across the world where there has been / ongoing earthquake risk reduction programmes to learn and share the experiences Replicate TVERMP in other growing urban centers across the country

Implementation Strategy

Reducing earthquake risk in Thimphu valley will require a holistic approach for addressing identified underlying risks in the valley. This will require participation of various ministries and departments and the vulnerable communities themselves to undertake and implement specific risk reduction activities. During the implementation of TVERMP, it is important to have effective coordination among various ministries and departments. The TVERMP will require strong coordination with the Department of Local Governance, Ministry of Home and Cultural Affairs, which is the national focal agency for disaster management. In particular, there is a need to establish linkage with the Integrated Disaster Risk Management Programme being spearheaded by MoHCA.

Technical and financial assistance will be required to implement the action plan hence it would be necessary to establish partnership with the various technical agencies, donors and other UN agencies.

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Seismic Hazard Assessment and Mitigation in Bangladesh

International Centre for Urban Safety Engineering, Tokyo

Background

Bangladesh and the northeastern Indian states have long been one of the seismically active regions of the world, and have experienced numerous large earthquakes during the past 200 years. Lots of seismo-tectonic studies have been carried out in this areas comprising the Indo- Burman ranges and their western extension and in the northern India. A seismicity map of Bangladesh and its adjoining areas has also been prepared by researchers, BMD and GSB. Bangladesh has been classified into three seismic zones with zone-3 the most and zone-1 the least vulnerable to seismic risks as shown under a separate section on seismic hazard assessment and mitigation in South Asia, presented in this volume. The following are extracts from papers published by researchers in Bangladesh as mentioned in references.

Introduction

Although Bangladesh is extremely vulnerable to seismic activity, the nature and the level of this activity is yet to be defined. In Bangladesh complete earthquake monitoring facilities are not available. The Meteorological Department of Bangladesh established a seismic observatory at Chittagong in 1954. This remains the only observatory in the country.

Accurate historical information on earthquakes is very important in evaluating the seismicity of Bangladesh in close coincidences with the geotectonic elements. Information on earthquakes in and around Bangladesh is available for the last 250 years. The earthquake record suggests that since 1900 more than 100 moderate to large earthquakes occurred in Bangladesh, out of which more than 65 events occurred after 1960. This brings to light an increased frequency of earthquakes in the last 30 years. This increase in earthquake activity is an indication of fresh tectonic activity or propagation of fractures from the adjacent seismic zones.

Before the coming of the Europeans, there was no definite record of earthquakes. Following is a chronology of important earthquakes from 1548.

Chronology

1548	The first recorded earthquake was a terrible one. Sylhet and Chittagong were violently shaken, the earth opened in many places and threw up water and mud of a sulphurous smell.
1642	More severe damage occurred in Sylhet district. Buildings were cracked but there was no loss of life.
1663	Severe earthquake in Assam which continued for half an hour and Sylhet district was not free from its shock.
1762	The great earthquake of April 2, which raised the coast of Foul island by 2.74m and the northwest coast of Chedua island by 6.71m above sea level and also caused a permanent submergence of 155.40 sq km near Chittagong. The earthquake proved very violent in Dhaka and along the eastern bank of the Meghna as far as Chittagong. In Dhaka 500 persons lost their lives, the rivers and jheels were agitated and rose high above their usual levels and when they receded their banks were strewn with dead fish. A large river dried up, a tract of land sank and 200 people with all their cattele were lost. Two volcanoes were said to have opened in the Sitakunda hills.
1775	Severe earthquake in Dhaka around April 10, but no loss of life.
1812	Severe earthquake in many places of Bangladesh around May 11. The earthquake proved violent in Sylhet
1865	Terrible shock was felt, during the second earthquake occurred in the winter of 1865, although no serious damage occurred.
1869	Known as Cachar Earthquake. Severely felt in Sylhet but no loss of life. The steeple of the church was shattered, the walls of the courthouse and the circuit bungalow cracked and in the eastern part of the district the banks of many rivers caved in.
1885	Known as the Bengal Earthquake. Occurred on 14 July with 7.0 magnitude and the epicentre was at Manikganj. This event was generally associated with the deep-seated Jamuna Fault.
1889	Occurred on 10 January with 7.5 magnitude and the epicentre at Jaintia Hills. It affected Sylhet town and surrounding areas.
1897	Known as the Great India Earthquake with a magnitude of 8.7 and epicentre at Shillong Plateau. The great earthquake occurred on 12 June at 5.15 pm, caused serious damage to masonry buildings in Sylhet town where the death toll rose to 545. This was due to

	the collapse of the masonry buildings. The tremor was felt throughout Bengal, from the south Lushai Hills on the east to Shahbad on the west. In Mymensingh, many public buildings of the district town, including the Justice House, were wrecked and very few of the two-storied brick-built houses belonging to zamidars survived. Heavy damage was done to the bridges on the Dhaka-Mymensingh railway and traffic was suspended for about a fortnight. The river communication of the district was seriously affected (Brahmaputra). Loss of life was not great, but loss of property was estimated at five million Rupees. Rajshahi suffered severe shocks, especially on the eastern side, and 15 persons died. In Dhaka damage to property was heavy. In Tippera masonry buildings and old temples suffered a lot and the total damage was estimated at Rs 9,000.
1918	Known as the Srimangal Earthquake. Occurred on 18 July with a magnitude of 7.6 and epicentre at Srimangal, Maulvi Bazar. Intense damage occurred in Srimangal, but in Dhaka only minor effects were observed.
1930	Known as the Dhubri Earthquake. Occurred on 3 July with a magnitude of 7.1 and the epicentre at Dhubri, Assam. The earthquake caused major damage in the eastern parts of Rangpur district.
1934	Known as the Bihar-Nepal Earthquake. Occurred on 15 January with a magnitude of 8.3 and the epicentre at Darbhanga of Bihar, India. The earthquake caused great damage in Bihar, Nepal and Uttar Pradesh but did not affect any part of Bangladesh. Another earhquake occured on 3 July with a magnitude of 7.1 and the epicentre at Dhubri of Assam, India. The earthquake caused considerable damages in greater Rangpur district of Bangladesh.
1950	Known as the Assam Earthquake. Occurred on 15 August with a magnitude of 8.4 with the epicentre in Assam, India. The tremor was felt throughout Bangladesh but no damage was reported.
1997	Occurred on 22 November in Chittagong with a magnitude of 6.0. It caused minor damage around Chittagong town.
1999	Occurred on 22 July at Maheshkhali Island with the epicentre in the same place, a magnitude of 5.2. Severely felt around Maheshkhali island and the adjoining sea. Houses cracked and in some cases collapsed.
2003	Occurred on 27 July at Kolabunia union of Barkal upazila, Rangamati district with magnitude 5.1. The time was at 05:17:26.8 hours.

Status of Seismic Hazard Assessment

Bangladesh is surrounded by the regions of high seismicity which include the Himalayan Arc and Shillong Plateau in the north, the Burmese Arc, Arakan Yoma anticlinorium in the east and complex Naga-Disang-Jaflong thrust zones in the northeast. It is also the site of the Dauki Fault system along with numerous subsurface active faults and a flexure zone called Hinge Zone. These weak regions are believed to provide the necessary zones for movements within the basin area.

In the generalised tectonic map of Bangladesh the distribution of epicentres is found to be linear along the Dauki Fault system and random in other regions of Bangladesh. The investigation of the map demonstrates that the epicentres are lying in the weak zones comprising surface or subsurface faults. Most of the events are of moderate rank (magnitude 4-6) and lie at a shallow depth, which suggests that the recent movements occurred in the sediments overlying the basement rocks. In the northeastern region (Surma Basin), major events are controlled by the Dauki Fault system. The events located in and around the Madhupur Tract also indicate shallow displacement in the faults separating the block from the Alluvium.

The first seismic zoning map of the subcontinent was compiled by the Geological Survey of India in 1935. The Bangladesh Meteorological Department adopted a seismic zoning map in 1972. In 1977, the Government of Bangladesh constituted a Committee of Experts to examine the seismic problem and make appropriate recommendations. The Committee proposed a zoning map of Bangladesh in the same year.

In the zoning map, Bangladesh has been divided into three generalised seismic zones: zone-I, zone-II and zone-III. Zone-I comprising the northern and eastern regions of Bangladesh with the presence of the Dauki Fault system of eastern Sylhet and the deep seated Sylhet Fault, and proximity to the highly disturbed southeastern Assam region with the Haflong thrust, Naga thrust and Disang thrust, is a zone of high seismic risk with a basic seismic co-efficient of 0.08. Northern Bangladesh comprising greater Rangpur and Dinajpur districts is also a region of high seismicity because of the presence of the Jamuna Fault and the proximity to the active east-west running fault and the Main Boundary Fault to the north in India. The Chittagong-Tripura Folded Belt experiences frequent earthquakes, as just to its east is the Burmese Arc where a large number of shallow depth earthquakes originate. Zone-II comprising the central part of Bangladesh represents the regions of recent uplifted Pleistocene blocks of the Barind and Madhupur Tracts, and the western extension of the folded belt. The Zone-III comprising the southwestern part of Bangladesh is seismically quiet, with an estimated basic seismic co-efficient of 0.04.

Mitigation approach

The occurrence of earthquakes in an earthquake prone region cannot be prevented. However, as far as Bangladesh is concerned a detailed geological map including the delineation of all crustal faults and lineaments is of prime importance. The Aeromagnetic survey of Bangladesh has already provided the pattern and distribution of such faults and lineaments. By now the delineation of faults within the Tertiary sections are well established, but the situation within the Quaternary section is quite uncertain. It is evident that Quaternary sediments are affected by various earthquake events in Bangladesh pertaining to uplift, subsidence, ground deformation and massive liquefaction, therefore such tectonic features need to be mapped in Quaternary sediments.

Source: MH Ali and JR Choudhury, Assessment of seismic hazard in Bangladesh, Disaster Research Training and Management Centre, Dhaka University, Dhaka, 2001; JR Choudhury and MH Ali, Seismic Zoning of Bangladesh, paper presented in the Seminar on Recent Development Earthquake Disaster Mitigation, Organised by IEB and TAEE, Dhaka, 1994; KM Hossain, Tectonic significance and earthquake occurrences in Bangladesh, 7th Geological Conference, Bangladesh Geological Society, 1989.

Recommendations for Seismic Hazard Mitigation in Bangladesh

The following are general recommendations provided by Prof. M. A. Ansary, Department of Civil Engineering, BUET, Bangladesh based on the activities and research work undertaken by BUET, Bangladesh Earthquake Society, government and some non-government organizations, a few other public universities of Bangladesh and media who are also playing a major role in earthquake risk mitigation efforts.

Awareness and capacity building

- Increase public awareness through education (school children), earthquake drills, interactive website, mass-media, publication, training etc.
- Training of building inspectors, community leaders, construction workers and masons.
- Updating earthquake engineering course curriculum.

Earthquake engineering research

- Installation of free field accelerographs and seismographs for engineering and seismology studies.
- Seismic hazard assessment based on free field data and source models.
- Vulnerability assessments of structures using structural analysis and nondestructive testing.
- Develop laboratory and testing facilities.
- Development of indigenous and cheap retrofitting measures. Microzonation of urban areas based on different soil effects.
- Updating building code.

Earthquake resistant construction

- Legal enforcement of building code.
- Proper use of ductile steel and lateral force resisting systems.
- Building insurance to promote earthquake resistant construction.
- Retrofitting critical structures such as schools, hospitals and fire offices.
- Urban and regional planning to mitigate earthquake effects.

Post-earthquake response

- Develop automatic safety shutdown system for electricity, gas, telephone and water supply system whenever the ground shaking exceeds a certain limit.
- Develop facilities for post earthquake search and rescue operation.
- Local people and organizations most effectively do rescue of victims because they are able to carry this out more quickly than outside agencies. Community based voluntary group should be trained who can actively participate in rescue operation just after an earthquake disaster.
- Prepare contingency plans.
- Coordination among different interest groups involved in the post earthquake rescue effort.
- Arrangement of emergency medical treatment facilities for injured people.

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Assessment and Diagnosis of Existing Multistoreyed Buildings in SAARC Coutries for Desired Seismic Performance

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Abstract

In recent earthquakes in India and Pakistan, not only the non-engineered masonry buildings have collapsed, the multi-storeyed RC buildings have also shown the large-scale damage and therefore highlighted the vulnerability of our existing multi-storey buildings to earthquakes. Most of the urban living is in multistoried flats and many of these are on stilt. People living in multi-storeyed flats are very much concerned about their safety. In this paper the problem of assessment and diagnosis of multi-storeyed buildings constructed in South-East Asian countries against earthquakes has been addressed.

Introduction

Cities are growing, urban seismic risk is rapidly growing, particularly in most SAARC countries and cities are more and more vulnerable to disasters. Direct hits by a major earthquake in towns and cities specially mega cities, losses could be in billions. Mega cities are like ticking time bomb.

Fig. 1: A typical multi-storeyed Building

Poor performance of urban and semi urban buildings in recent Indian earthquakes have been observed specially in the Gujarat earthquake where multi-storey buildings had crumbled like houses of cards within a matter of seconds. Generally, most of the multi-storey buildings are in the urban areas and mostly less than 20 storeys. A typical muli-storey building is shown in Fig.1. Since, the IS codes on earthquake resistant design are not mandatory and construction practices are not very strict, most of the existing multi-storey buildings may not be earthquake safe. Many of them may be asking themselves, how seismically strong are they? The answer, thankfully, is that they too are as strong as we make them out to be. Many of the existing old structures may have faulty original design, extensions, alterations, encroachments, degradation of material over the time and therefore pose enormous seismic risk in particular to human lives and property. It is therefore important to assess the vulnerability of the existing multi storey buildings using well-established accepted procedures.

We may accept minor damages but no collapse during a major earthquake. That is a good enough reason why we should get our homes assessed for its earthquake resistance. But where do we begin? Depending upon the each structure and seismic zone and only a structural expert will be in a position to tell if the basic design of the house along with the structural drawings and soil data are available.

Seismic Evaluation of Buildings

According to the Vulnerability Atlas of the country, more than 80% houses are non-engineered construction, which are mainly load bearing buildings. However, there are many RC framed urban buildings which have been constructed without any consideration to resist earthquake forces or without using the current codal practices on Earthquake Resistant Design. For such a large number of seismically deficient buildings, a quick assessment method and guidelines have to be developed together with training and capacity building.

The building typologies and epochs of their construction need to be studied with their vulnerability analysis under various seismic intensities. Various factors contributing to the vulnerability of buildings are (i) construction of non-engineered r.c. frame buildings where no engineer is consulted; (ii) faulty original design –lack of lateral resisting elements e.g. frames, shear walls; (iii) changes in Codal practices; (iv) inadequate detailing of reinforcement; (iv) extensions, alterations and encroachment; (v) increase in load during to usage; (vi) poor and deficient construction; (vii) lack of regular maintenance; and (viii) degradation of building material/ Corrosion.

Check the following: (i) Relative size – slenderness ratio; (ii) Weak storey – strength less than 80% of adjacent storey; (iii) Soft storey – stiffness less than 70% of adjacent storey; (iv) Geometry – not more than 30% change in horizontal dimension of the lateral resisting system; (v) Mass – not more than 50% change in effective mass from one storey to the next; (vi) Torsion – eccentricity not more than 1.5 times the building width; (vii) Diaphragm continuity – no sudden discontinuity; (viii) Plan irregularities projection of the structure beyond re-entrant corner greater than 15% of its plan dimension; (ix) Redundancy – structure should have large indeterminacy; and (x) Strong column-weak beam – the sum of the moment capacity of the columns shall be 10% more than that of beams at the frame joint

Possible Deficiencies in Existing R.C. Frame Buildings

Assessment during RVS requires engineering judgment and training. While carrying out assessment identification of structural system is foremost important. The buildings based on gravity and lateral load resisting system can be classified into (i) RC Moment Resisting Frame and (ii) RC Frame with Masonry Infill. Next step is to identify earthquake resistant features, potential deficiencies and weak links in each type and benchmark the performance in recent Indian earthquake for sample building in each category

Inadequate Foundation System: Buildings situated near the steep slope, on the filled up ground or loose ground, liquefiable soil are vulnerable. Foundation adequacy has to be checked for such conditions. Buildings lying close to the zone of landslide/rock slide area, near known fault and shear zone should also check the safety.

Inadequate planning and design**:** (i) Unsymmetrical buildings; (ii) Floating columns leading to sudden change in stiffness; (iii) Small width of columns (120 to 200 mm); (iv) Weakness due to orientation of columns/ beams; (v) Columns designed for axial load without any moments; (vi) Walls resting on slab without any beam; and (vii) Long cantilever.

Inadequate detailing and construction**:** (i) Lack of lateral load resisting elements: moment resisting frame, shear walls; and (ii) inadequate detailing of reinforcement from ductility considerations e.g. anchorage of longitudinal reinforcement, beam-column joint regions, lap splices placed in potential plastic hinge regions and transverse reinforcement in beams and columns (iii) inadequate diaphragm action of roof & floors; (iv) inadequate strength and ductility in soft storey; (v) poor quality of construction material and technology; (vi) treatment of non-structural components – infill walls, staircases, water tanks on roof; (vii) inadequate strength of footings and/or piles, and (viii) local construction practice - Strength of concrete, reinforcement properties, detailing practices, compressive strength of bricks and mortar.

Factors contributing to the torsion**:** The important facors contributing to the torsional behaviour of building are (i) unsymmetry in plan and elevation e.g shape of the building – L, E, T or irregular plans, (ii) location of lift core, (iii) regularity of columns on a typical floor, (iv) position of water tanks, heavy equipment on roof; (v) locations of infill walls

Evaluation of a building is required at two stages: (1) before the retrofitting, to identify the weaknesses of the building to be strengthened, and (2) after the retrofitting, to estimate the adequacy and effectiveness of the retrofit. Evaluation is a complex process, which has to take into account not only the design of the building but also the deterioration of the material and damage caused to the building, if any. The difficulties faced in the seismic evaluation of a building are threefold. There is no reliable method to estimate the in-situ strength of the material and components of the building. Analytical methods to model the behaviour of the building during an earthquake are either unreliable or too complex to handle with the available tools. The third difficulty is unavailability of a reliable estimate of the earthquake parameters, to which the building is expected to be subjected during its residual life. The ground motion parameters available in the present code have been estimated at a macro level and do not take into account the effect of local soil conditions, which are known to greatly modify the earthquake ground motion.

Vulnerability of Existing Buildings: Building design at various time interval followed different revision of the code varying not only in the seismic force level but also in the provisions for ductility.

SEISMIC Zone	1962/2002	1966/2002	1970/2002	1975/2002	1984/2002
III	0.28	0.53	0.60	0.72	1.0
IV	0.23	0.44	0.50	0.60	1.0
V	0.25	0.47	0.50	0.65	1.0

Importance factor =1.0; In 1984 Performance factor K=1.6; Soil type III; In 1970, 1975, 1984 Beeta is taken 1.5; Seismic coefficient for 2002 evaluated for R=3

UNIDO procedure: If the Available Seismic Resistance, ASR (as per seismic design resistance used or determined by fresh calculations for existing buildings) is found to be equal to or more than 80% of Minimum Seismic Resistance, MSR under current seismic code, the building need not be retrofitted.

The different steps in the seismic evaluation of a building are as following:

Structural Configuration

Visual inspection is the most important tool in the study of the actual condition of a building. Study of drawings is another source of information. The plan, elevation, sections of the building, design calculations, specifications and construction record are needed to be examined. Earthquakes have repeatedly demonstrated that simple structures have greater chance of survival.
Inadequate Application Technical Knowhow: Inadequate application of available engineering know-how due to ignorance, negligence and economic constraints has resulted in seismic unsafe buildings. In the event of practically non existent legislation about safe construction, the IS codes of practice are not complied.

***Non-uniform Configuration*:** Experience in past earthquakes has shown that the buildings with simple and uniform configurations are subjected to less damage. The geometric irregularities in horizontal and vertical directions weaken the building. A building with discontinuity is subjected to concentration of forces and deformations at the point of discontinuity, which may lead to failure of members at the junction and finally collapse of the building. However, due to practical and architectural considerations, it is not always possible to have a regular structural configuration in the horizontal and vertical planes and it has been the root of conflict between the architects and the structural engineers.

***Large Openings*:** Large openings in the infill walls reduces the stiffness.
High walls: High walls such as theatre, auditorium, churches, and temples are vulnerable. The transfer of seismic load to the ground has to be assessed in terms of lateral resisting systems such as frames, shear walls, stiffness, connections, joints and support conditions.

Floating Columns: The vertical and lateral load carried by the columns should be transferred to the soil through the foundation system. The columns floating (resting) on beam as shown in the Fig.2 is likely to damage severely since the beam supporting the column will be subjected to very high loads. Such construction should be avoided as far as possible.

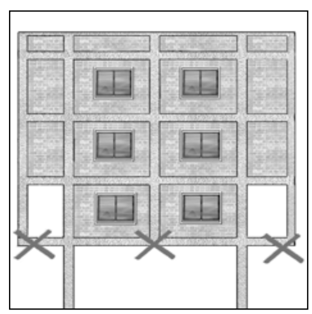

Fig. 2 Floating columns

Soft and weak storey: Due to scarcity of parking space in the cities the ground storey is kept open for parking. In framed buildings, usually the upper storeys have masonry infills as partitions, while the ground storey is having only the bare frame. This type of structural system, termed as Stilt, is very common in commercial, as well as, residential multi-storey buildings of big cities. The masonry infills present in the upper storeys, act as diagonal braces and increase the storey stiffness significantly. The absence of stiffness due to infills, at the ground storey makes it a soft storey. Figure 3 shows a ground soft storey multi-storey building which has undergone severe damage to

Fig.3: Soft ground storey failure

Fig. 4: Ten storey building with collapse of third storey

the columns. Figure 4 shows the weak storey failure. Sometimes, the ground storey is designed to house plazas and commercial compounds with large floor areas and high ceilings.

A few of the columns and shear walls are dropped at first storey and the height of the remaining columns is more than usual. This type of system results in further reduced stiffness of the ground storey, and poses great risk to the safety of the building, specially when subjected to earthquake forces. Such architectural designs resulting in extremely soft ground storeys may be debatable, but the scarcity of parking space in big cities is a real problem and there does not seem to be a solution for that, other than the stilt type construction. Therefore, the open ground storey buildings are going to remain and the structural engineers have to find solutions to this problem.

The recent earthquake of Bhuj has once again focussed on the problem of soft storey buildings, as a number of soft ground storey buildings in Ahmedabad, which is about 300 km away from the epicentre, have collapsed. Of course, the major reasons of collapse have been the poor detailing of reinforcement and the poor quality of construction. There were many other modes of failure of multi-storey RC framed buildings. But these weaknesses have been widely exposed in most of the soft ground storey buildings. This has forced to consider alternative designs providing sufficient stiffness to the ground storey and, at the same time, not hindering the parking functional requirement of parking space.

The soft and weak storey in commercial, apartment or office building or stilt parking without adequate stiff support at ground floor may result in a weak storey causing partial or total collapse. In masonry infilled frame building with open ground storey configuration the stiffness of the upper storeys is about three times the stiffness of the ground storey. This ratio may be much higher in case of buildings with columns or shear walls dropped at ground storey. Such storeys were originally visualized [(Fintal & Khan(1969)] to have shock absorbing effect to reduce the earthquake forces on multi-storey buildings. However the performance of such buildings in past earthquakes has shown that the ductility demand of first storey in such buildings is beyond the practicable limits [Chopra *et al*.(1973), Pekau(1975)]. The soft first storey building behaves as an inverted pendulum, resulting in very large lateral deformation of ground storey. Most of the lateral deformation of the building is concentrated in the ground storey, while the upper portion of the buildings is well within the elastic limit. The energy dissipation takes place mainly through the first storey.

In a multi-storey building the ground storey is subjected to the maximum storey shear. If the first storey is soft storey the columns of the first storey yield, first. The upper storeys of the building float over the first storey and this reduces the storey shear in the upper storeys due to base isolation effect. Therefore, the upper storeys, including the masonry infills, remain intact and elastic. Most of the energy dissipation takes place through the first storey only, which requires very large displacement, usually much beyond the capacity of the columns. The beams of the ground storey are protected from large inelastic deformations, due to presence of infills above. This essentially results in formation of an unstable mechanism. P-delta effect due to excessive displacement of the first storey and heavy weight of the upper storeys further increases the instability.

The codes [IS:1893(2002), IBC(20000] define a soft storey as having lateral stiffness less than 70% of the stiffness of the storey above or less than 80% of the average lateral stiffness of the three storeys above. If the stiffness is less than 60% of the stiffness of the storey above or less than 70% of the average lateral stiffness of the three storeys above, then, it is termed as Extreme Soft Storey.

Masonry Infill: The behaviour of masonry infills in frame buildings is complex. Several problems associated with the masonry infills have been observed in the past earthquakes. Out of these the soft storey effect is the most glaring. In developed countries the seismic codes tend to discourage the use of masonry panels as partitions. At the same time, some beneficial effects of masonry have also been reported. Some of the buildings with masonry infills have shown excellent seismic behaviour during past earthquakes. In developing countries masonry is still quite common to be used as partitions in framed buildings.

The complexity of the behaviour of masonry is further complicated by the absence of rigid contact between the masonry panel and the beam above and presence of openings for windows. The infills are brittle and weak compared to the RC frame members. These contribute to the stiffness of the structure in the initial stage of loading, but generally fail before the ultimate capacity of frame is reached. Therefore, the usual design practice has been to ignore the stiffness and strength contribution of the infills and design the bare frame for the earthquake loads.

If a frame has uniform in-fills throughout its height, it increases the stiffness of the building uniformly. This reduces the time period of the building and pushes it into the higher acceleration zone of the response spectra. Therefore, some of the codes require that the infilled frames should be designed for the average of the time periods of the infilled and the uncracked bare frame. However, it has been reported [Fardis(1998)] that such requirements may be too conservative and unduly penalizes the infilled structures.

Problem arises in case of a building with open first storey; where the first storey is kept open for parking purposes. The stiffness of the upper storeys, having masonry infills increases several times the stiffness of the first storey, resulting in the soft first storey configuration.

Even a building with uniform masonry infills, throughout its height may result in soft first storey configuration. As the masonry panels are weak, they fail, first in the ground storey. The failure of masonry infills in the ground storey changes the configuration to the soft first storey configuration where the ground storey columns yield while the upper storeys remain elastic, as the storey shear in the upper stories is reduced due to base isolation effect.

Seismic evaluation of adjacent buildings is also important. Adjacent buildings of unequal height may collide; floors may impact or fall over the adjacent buildings causing damage.
Estimation of in-situ strength, defects and degree of damage/deterioration is an important and complex task. A number of non-destructive techniques are available for this purpose such as ultra sonic pulse velocity, rebound hammer test etc. Most of the non-destructive tests are based on indirect measurement and require experience and skill in interpretation of results. Use of statistical methods is helpful in concluding about the in-situ strength of concrete and overall condition of the building.

The condition survey of a building has to take into account three types of deficiencies: (i) deficiency arising from the original design, (ii) deficiency due to construction defects and damage due to earthquake or fire, and (iii) deficiency due to deterioration of material with time. The deficiencies in the original design can be identified by studying the drawings and design calculations. Many buildings constructed during 60's and 70's have not been designed for earthquake forces. The defects during construction and damage caused during earthquake and fire can be first located by visual inspection. It will be followed by a detailed investigation may. Ultrasound pulse Velocity test is helpful in finding out the hidden cavities and delaminations. Corrosion of the reinforcing steel is the main cause of deterioration of RC structures with time. Corrosion causes reduction of steel area, loss of bond and cracking and spalling of cover concrete. It can be located by the typical cracking pattern and tests such as half-cell potential measurement.

Earthquake Intensity

Earthquake intensity at a site can be estimated from the seismic zoning map of India. For better estimation site-specific studies are carried out. Seismic microzonation of major cities of India is being carried out. Once the seismic microzonation maps are available more accurate estimation of earthquake intensities will be possible.

Geological Conditions

Vulnerability of building has to be assessed with respect to soil liquefaction, proximity to slope failures/ rock-fall areas and proximity to surface fault rupture. There is a need for microzonation to assess vulnerability to greater detail and accuracy.

Foundation Capability

Structures have to be assessed for its performance, settlement, depth of foundation, deterioration due to weathering or age, capacity of foundation, stability against overturning, ties between foundation elements, load path for transfer of seismic forces to soil and special requirements in sloping sites.

Non-structural components

Parapets, sunshades, projections, fixtures, cladding etc. have to be assessed for their capacity to withstand earthquake forces. Safety of non-structural components is particularly important in case of buildings such as Hospitals, Telephone exchanges, control buildings, etc. The failure of fixtures and connections may lead to not only the disruption of the function but also the loss of life due to disruption as well as due to direct injury from the falling component.

Partitions and infills are another component, which are usually considered as non-structural in the design. Their safety is not ensured in design. Failure of masonry infills in out of plane bending may be fatal to the inmates.

Methods of Evaluation

The evaluation of a building has to take into account a number of parameters described above. A rigorous evaluation of a building is involved and time consuming. Several methods of evaluation have been suggested namely, Screening method, Field Evaluation method, Approximate Analytical method and Detailed Analytical Evaluation method for assessing the seismic vulnerability of an existing building.

Rapid Visual Screening - RVA (L1)

The Rapid Visual screening is carried out for all considered buildings. It permits quick visual vulnerability assessment
The purpose of the Rapid Visual Assessment (RVA) is to determine the adequacy of the structural facility as to whether the facility will be able to withstand the expected earthquake. For scenario earthquakes, performance levels for existing building stock need to be assessed. Rapid vulnerability assessment is the first necessary step but may not be sufficient to establish building stock performance levels.

The site where the structure is located is assigned a modified Mercalli Intensity (MMI) for the expected earthquake. If this data is not available, then it will have to be worked out based on geological and seismological studies. Necessary information for evaluation of structure is obtained either by conducting a field survey or from building typology, if available or from both. If plan is available, then the field party must check and verify the present status of the building.
In this method, buildings are evaluated qualitatively in terms of structural characteristics, structural configuration, and the degree of deterioration of the building. This method is rapid and inexpensive and helps in identifying structures, which are clearly hazardous and the structures for which detailed hazard evaluation is sought.

The most pertinent information required to establish rating for building is collected. The information required are (i) general data, (ii) site related data, (iii) structural data and (iv) data about non-structural elements. Based on these data, capacity ratio of each structure is worked out in terms of intensity rating and structural system rating. If the capacity ratio is worked out to be more than one than the structure is expected to withstand the expected earthquake, otherwise the structure is weak and need strengthening. This method is considered reasonable and quite adequate for a large scale survey of building in areas of potential seismic danger.

Simplified Vulnerability Assessment – SVA (L2)

It requires limited simplified engineering analysis to estimates the building drift. In this method, the capacity of an existing building to resist lateral forces is evaluated by determining the stress ratios of its structural and non-structural elements. Stress ratio of an element is defined as the ratio of the stresses induced by the seismic loading to that of the allowable stresses. In brief, the method involves identification of critical elements of the building such as columns, walls, chord members etc., and determining their stress-ratios for a combination of lateral and vertical loads. These are then compared with the acceptable ratings and the capacity of the building assessed as good, fair, poor or very poor.

Detailed Vulnerability Assessment – DVA (L3)

It requires detailed nonlinear analysis on computer as for new buildings. It is recommended for important buildings A detailed evaluation is made for those structures which are found deficient in the initial assessment. For detailed assessment, static and seismic analysis may have to be carried out. Detailed analytical method evaluates the damage on the basis of energy capacity of the structure and expresses as percentage of total damage on a storey by storey basis. Damage is computed separately for structural, non-structural and glass elements. For structural and glass elements the damage is evaluated as a function of inter storey drift while for non-structural elements the damage is evaluated on the basis of an estimated floor Modified Mercalli Intensity. The maximum dynamic response of the building to the applied load is calculated by response spectrum approach considering the fundamental mode only. The performance of the building is evaluated with regard to strength and ductility.

Diagnosis

Actual diagnosis of vulnerability can be assessed by working out the capacity and demand of a building. Capacity curve is a plot of seismic shear "V" and lateral deflection of the building at roof level obtained by an approximate nonlinear, incremental analysis. A computer model is created and then lateral storey forces is applied either at the top or along the height of the building proportional to fundamental mode shape of the building. The building is then analysed for gravity and lateral loads to obtain member forces including p-delta effects. The base shear, roof displacement, member forces and member displacements are recorded. Cumulative base shear, roof displacement, member forces and member displacements are calculated. Analsis is repeated till the structure becomes unstable or the deformation of members is such that loss of gravity load carrying capacity takes place.

The demand curve is elastic response spectra reduced to the damping ratio corresponding to the deformation stage of the building. For comparison the demand capacity needs to be plotted in the same coordinates. The acceleration-displacement response spectra (adrs) is the convenient format for this purpose.

Conclusions

The problem in most of the SAARC countries is similar in respect of safety of the RC buildings due to existing construction practice. The problem of seismic evaluation and assessment of buildings has been discussed. Strengthening techniques for masonry and RC buildings have been discussed separately. Two alternative methods for strengthening of soft storey building have been provided. Soft first storey buildings require very high ductility of the first storey columns, which is usually beyond the practicable limits. Such buildings have proved to be unsafe during past earthquakes.

Soft storey configuration should be avoided by providing frame-shear structure at the ground storey. To avoid soft first storey configuration in uniformly infilled frame buildings, a minimum quantity of shear walls should be provided. Alternative designs with energy dissipating devices in the first storey are under development.

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South Asia Regional Initiative for Earthquake Risk Reduction and Recovery Preparedness

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In the South Asian region, earthquakes occurring in various places in recent years are resulting in huge damages. A limited capacity of the national organizations and low awareness in the most vulnerable communities adds to the impact of disasters. Public buildings (schools, hospitals, community centres, etc...) and private houses in the region are in many cases highly vulnerable to earthquakes[1]. As a result, large numbers of school children died, and women, who tend to remain at home in sex-segregated societies, were more affected than men in the recent south Asian earthquakes. Increased efforts are required for earthquake preparedness and mitigation to reduce the risk of future disasters. Findings from various evaluations[2] on earthquake recovery programs show that in many cases, post disaster recovery initiatives are re-building risks and point at significant gaps in the knowledge, capacities and policy on risk reduction and recovery among key stakeholders in the region. Mega earthquakes in Pakistan and India demonstrate the need for a well coordinated earthquake risk reduction and recovery preparedness initiative for the South Asia region.

Taking into account the negative impact of the natural hazards and disaster in the regional development, **United Nations Development Programme (UNDP)** initiated a regional progarmme for Earthquake Risk Reduction and Recovery Preparedness with the funding support from the Government of Japan. The Programme was proposed in the context of the International Recovery Platform (IRP) for the fulfillment of the Hyogo Framework for Action (HFA). Guiding principles and priority activities for disaster risk reduction are comprehensively described in the Hyogo Framework for Action 2005 – 2015: *Building the resilience of communities and nations to disasters ("Hyogo Framework").*

The programme aims to strengthen the institutional and community capacity to plan and implement earthquake risk reduction strategies integrating disaster preparedness, mitigation and post disaster recovery in **five high risk South Asian countries** (*Bhutan, Bangladesh, India, Nepal and Pakistan*). The programme seeks to support regional cooperation for disaster risk reduction and recovery preparedness in the context of **SAARC Framework for Disaster Management[3]** which is also aligned with the implementation of the Hyogo Framework for Action (HFA).

The programme includes five key outputs: 1) to conduct earthquake risk, vulnerability and capacity assessment in the project areas to support the Governments and communities; 2) to enhance

[1] Do not meet the criteria for Earthquake resistant construction good practice

[2] Gujarat, Bam, Indonesia EQ report, IRP recovery lessons learned book, etc...

capacities of government Institutions and communities living in high risk areas to adapt and implement earthquake preparedness planning and safe construction practice using appropriate earthquake resistant construction guidelines; 3) to strengthen the capacity of the Governments in disaster recovery preparedness (at pre disaster stage) to support enhanced recovery operations , 4) to develop capacities of the governments to implement national disaster management framework by supporting locally appropriate solutions for earthquake risk reduction; and, 5) to enhance the knowledge base of disaster stakeholders of countries and region by sharing, exchanging and documenting of lessons and best practices for policy feedback and advocacy.

It is expected that the progarmme participants will gain experience on the planning and implementation of Earthquake risk reduction strategies based on **locally and community defined** needs, constraints and proposed solutions identified through Risk, Vulnerability and Capacity Assessment. The programme will address regional cooperation and coordination through the sharing of experience, lessons on best practices among the region in cooperation with the SAARC secretariat and SAARC regional centers. The progarmme will also ensure appropriate Technical Assistance for the regional and country level projects using regional and International specialized agencies, NGOs and networks working on disaster risk reduction and recovery initiatives.

The programme has been built on a two tier approaches for the implementation, a) Country level projects to support the national disaster management framework of countries, b) Coordination support initiatives for Regional sharing of experience among and Technical Assistance for regional and country level projects. The regional component has been undertaken in collaboration with SAARC Disaster Management Centre (SDMC) and other regional partners. The Regional Programme is seeking International technical assistance through the regional and international institutions, particularly from Japan in view of its extensive experience on earthquake risk reduction. A partnership agreement has been made with Asian Disaster Reduction Center (ADRC) to outsource Japanese expertise for the technical assistance for programme.

ERRP interventions at the national level**:**
Under the framework of ERRP regional programme, project targeted countries are implementing following activities:

Bangladesh:

Bangladesh is a part of Bengal basin which is one of the most seismically active zones in the world. Located in the confluence of India, Burma and Eurasia plate, the land is extremely prone to earthquakes and in the past has experienced some of the worst earthquakes recorded. The catastrophic earthquakes of 1962 and 1982 are believed to have been partially responsible for the diversion of the old Brahmaputra River, from the west of its main distributory (Arial Khan), to the present Pandma Channel. Since 1860 over 20 shallow and intermediate earthquake epicenters have been recorded in Bangladesh and the states. Seismically Bangladesh can be classified into three zones. The vulnerability to earthquakes varies across the country, with Zone 1 being the most

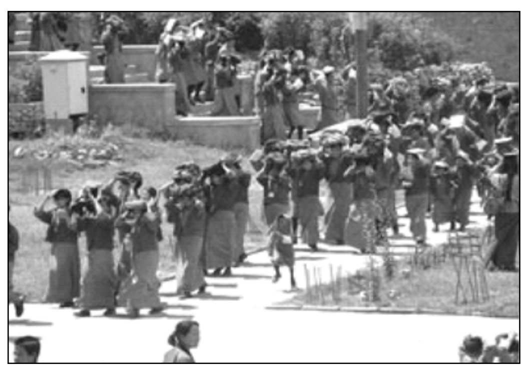
[3] Adapted in the 13th SAARC summit

at risk. No area of Bangladesh is immune to earthquakes.
Zone 1: North and Northeast (Sylhet, Mymensingh, Rangpur, etc) is the most vulnerable;
Zone 2: Northwest to Southwest (Dhaka, Chittagong, Dinajpur, Bogra, Tangail, etc); and
Zone 3: The remainder of the country

Over the past 150 years Bangladesh, and the surrounding region, has experienced seven major earthquakes (Mb=7). More recently, a number of moderate to serve earthquakes have occurred in and around Bangladesh. The Sylhet earthquake (Mb=5.6) on 8 May 1997, the Bandarban earthquake (Mb=6.0) on 21 November 1997, the Moheshkhali earthquake (Mb=5.1) on 22 July 1999 and the Barkol (Rangamati) earthquake (Mb=5.5) in July 2003 caused loss of life and destruction of buildings and infrastructures.[4]

Given the context of vulnerability in the Chittagong area, Government of Bangladesh with the support of UNDP initiated an earthquake risk reduction project in three districts of Chittagong Hill Tracts (Bandarban, Khagrachari, and Rangamati). The project includes five key outputs: 1) Standard seismic hazard and vulnerability maps for Chittagong Hill Tract (CHT) districts developed; 2.) Institutional and community capacity building for earthquake resistant construction, preparedness and mitigation strengthened; 3.) Public awareness campaigns organized and selected communities in three Hill Districts are better equipped to cope with earthquakes; 4.) Seismic safety survey of the existing vital structures in the three Hill Districts conducted, the most vulnerable public buildings identified and documentary knowledge product developed; 5.) Sharing and exchange of national and regional information, lessons and best practices for policy feedback and advocacy facilitated. The project activities will be implemented in three districts of Chittagong Hill Tracts. This project has been implementing under the Framework of Chittagong Hill Tract Development Facility (CHTDF).

Bhutan



Bhutan lies in one of the most seismically active zones of the world. Besides, the rugged mountain terrain, fragile geologic conditions and extreme climates make Bhutan inherently vulnerable to natural disasters such as flash floods and landslides. Studies indicate that the majority of Bhutan is either in Zone IV or V[5]. Records suggest that while four great earthquakes of magnitude exceeding 8 on the Richter scale occurred during 1897, 1905, 1935 and 1950. The earthquake that struck eastern Bhutan on February 24, 2006 are a reminder of Bhutan's vulnerability such disaster. Considering the underlying risk of earthquake, the Government of Bhutan with the support of UNDP proposed earthquake risk reduction project for the Thimpu, Phoentsholling, Gelephu and Samdrup Jongkhar districts.

[4] JRC 2006

[5] According to bureau of Indian Standards

The key interventions of the project includes, i) Develop / Review Standards, Codes and Guidelines for Seismic Evaluation and retrofitting, ii) Identification of Earthquake Risk and Vulnerability through assessment, iii) Institutional and community capacity building for earthquake preparedness and mitigation, iv) Implement model projects to support seismic safe construction/retrofitting of selected public buildings, v) To strengthen the capacity of the government in disaster recovery preparedness to support enhance recovery operation in post disaster situation, vi) To support locally appropriate solutions for earthquake risk reduction in Bhutan, vii) Facilitate sharing and exchange of national and regional information, lessons and best practice for policy feedback and advocacy.

Under the leadership of a National Project Director, the project has been implementing by the Disaster Management Department of Ministry of Home and Cultural Affairs and the Standard and Quality Control Authority, Ministry of Works and Human Settlements.

India

India has traditionally been vulnerable to natural disasters due to its unique geo-climatic conditions especially earthquakes, which is considered to be among the most destructive with the potential of inflicting huge losses to life and property. Around 60% of the country's landmass is prone to moderate, high or severe earthquake risks. Almost the entire northeast region, northern Bihar, Himachal Pradesh, Jammu & Kashmir and some parts of Gujarat are in seismic zone V, while the whole Gangetic plain and some parts of Rajasthan including the capital of the country are in seismic zone IV. The ***GOI-UNDP Disaster Risk Management (DRM) Programme*** was developed in 2002 to support Government of India's National Disaster Management Framework. The programme is being implemented in 169 multi -hazard prone districts in 17 selected states of the country. The earthquake risk reduction project was proposed under the GOI-UNDP DRM programme with an objective of "*Strengthen* the capacities of construction practitioners on multi-hazard resistant technology in selected multi-hazard prone districts of India, and promote safe construction practices in the 18 earthquake prone districts in *Bihar, Delhi and Uttaranchal*.

Bihar: Entire northern part of Bihar, being in the highly earthquake susceptible zone IV & V, is prone to high intensity earthquakes. 25-30 districts falling under seismic zone IV & V which makes it highly prone to earthquake. The earthquake damage potential gets further enhanced due to the liquefaction potential.

Delhi: The State lies in seismic zone IV [high earthquake damage risk zone] and is highly vulnerable to earthquake due to the existence of huge improperly constructed building stock, informal settlements, high population density, narrow and inaccessible lanes, haphazard and unplanned construction patterns etc.

Uttaranchal: The state of Uttaranchal is among the most seismically active parts of India and by virtue of its unique geographical setting is also prone to hazards such as landslides, cloudbursts and flash-floods. Many events of M5.5 or more have struck the region since 1900. The state straddles several active parallel thrust faults that form the ranges of the Himalayan mountain range.. So far, in the recent years (1990 onwards) Uttaranchal has experienced two major earthquakes (magnitude>6) in Uttarkashi (1991) and Chamoli (1999)

Major interventions of the project includes, i) Capacity building and skill upgradation of various professional [engineers, architects and masons] on hazard resistant technologies, ii) Demonstrate appropriate disaster resistant construction technologies for vulnerability and risk reduction, iii) Facilitate exchange of knowledge on best practices and construction designs and technologies for earthquake vulnerability reduction.

Nepal

Natural Disaster is common in Nepal. The country is geographically young and still evolving. Therefore, landsides and deep and shallow earthquakes are common and frequent. The increase in population and the change in its distribution also meant that the country is now faced with a new set of natural disaster risks, which are , i) earthquake (potentially lethal, liquefaction becoming a serious cause), ii) Landslides induced by earthquakes, torrential rains, and natural geological change, iii) Floods and flash floods, etc. Earthquake poses a special threat to Nepal, particularly in urban and suburban areas. According to BCPR report, Disaster Reduction: A challenge for development (2004), Nepal stands 11th rank in the world vulnerability to earthquake hazards and seismic faults passing through Nepal makes the entire country susceptible to this phenomenon. The ERRP project for Nepal has been designed to enhance institutional and community capacities for ERR in the five municipalities (Hetauda, Biratnagar, Pokhara, Birendranagar and Dhangadhi) located in five geographical regions of Nepal.

The proposed interventions of the project includes) Earthquake risk, vulnerability and capacity assessment conducted in the project areas, especially from gender and poverty perspective, to support the government and communities; ii) Capacities of government institutions and communities living in high risk areas enhanced to adapt and implement earthquake preparedness planning and safe construction practice using appropriate earthquake resistant construction guidelines; iii) Capacities of the government strengthened in disaster recovery preparedness to support enhanced recovery operations in post-disaster situations; iv) Capacities of the government developed to implement national disaster management framework by supporting locally appropriate solutions for earthquake risk reduction proposed by Nepal.

Pakistan

The areas comprising Pakistan have suffered four major earthquakes in the 20th century including the great Quetta earthquake of 1935, the 1945 earthquake off the coast of Makran, the 1976 earthquake in Northern areas, and the October 2005 Kashmir earthquake. In between these major events, the Northern areas and Kashmir have experienced many small quakes with localized impact.[6] The October 2005 earthquake highlighted the risk exposure and vulnerability of Pakistan. There is a need to establish and strengthen institutional mechanisms for Earthquake Risk Reduction at the city level in the affected areas. Under the ERRP Progarmme framework, UNDP in collaboration with National Disaster Management Authority (NDMA) Government of Pakistan proposed Earthquake Vulnerability Reduction and Preparedness (EVRP) project to support the process of integration of EVR into local development. The project interventions are being implemented in Muzafarabad and Mansera towns under AJK Province.

The key activities include, i) Conduct Earthquake risk assessment (ERA) in selected towns/ municipalities to support governments and communities to identify earthquake vulnerabilities and capacities, ii) Established Disaster Management Cell (MMDC) Muzaffarabad and Mansehra Municipalities:, iii) Formulation of Muzaffarabad and Mansehra Earthquake Risk Scenarios and Earthquake Vulnerability Reduction Plans including a land-use plan, iv) Development of easily understandable and applicable guidelines and technologies on earthquake safer construction, v) Capacity building for Municipal authorities integrating earthquake vulnerability reduction in the reconstruction process and development practice, vi) Awareness of public officials and communities to earthquake risk through demonstration projects and public awareness campaigns, vii) Reflective learning practices institutionalized for structural learning, improved knowledge management/ resource development and wider dissemination.

Key achievements:

The ERRP participating countries made considerable progress in implementing their national level projects. In India project has conducted capacity development training for the district engineers and masons of two project states (Delhi and Uttranchal) along with practical demonstration. Project also initiated constructing earthquake safe public structure following EQ safe construction guidelines. Nepal has completed capacity assessment of the municipalities and government department at the district level and initiated municipality level training programme for the engineers, supervisors and masons. Currently ERRP Nepal is conducting training programme for the municipality engineers and construction supervisors on safe construction supervision.

[6] NDM Framework for Pakistan (Draft), NDMA, Government of Pakistan

Bangladesh

Bangladesh has completed the project foundation work that includes establishment of project management team, development of technical packages for national coordination, etc... The Project Management Team of ERRP Bangladesh is planning to organize a project inception workshop in collaboration with relevant ministries in late December'08. Pakistan has completed risk and vulnerability assessment of designated public buildings and private houses in the project areas. They have also completed social vulnerability assessment in the same areas. Currently the project team is working on developing the easily understandable and applicable guidelines on earthquake safe construction. Bhutan has organized training on disaster preparedness highlighting earthquake risk for the school teachers of Thimpu district and conducted mock drills on EQ preparedness for the school children of Thimpu. They have also organized a *Table Top Exercise* to review the preparedness aspects in relation to Earthquake, GLOF, etc...

Regional Project Coordination office (RPCO) has recently organized an inception regional workshop on 10-12 August, 2008 in Kathmandu to facilitate the process of information exchange and technical cooperation for the programme. The RPCO has made series of consultation with country project team in collaboration with ADRC, the TA partner of ERRP, to indentify the technical assistance need for country level projects. All Country team has submitted their TA requirements along with TOR for the TA activities.

Conclusion:

ERRP is a hazard specific first regional programme addressing national level risk reduction issues in a regional context. The diverse and multi stakeholder involvement in ERRP widen the benefit of the project in the region. Despite many implementation challenges, programme has manifested considerable impact in enhancing awareness and capacity of communities and national and regional disaster stakeholders on earthquake Risk Reduction. The programme is seeking effective linkage with national and regional experts and institutions to ensure appropriate and applicable technical support for sustainable ERR initiatives. It is expected that the programme will have remarkable contribution for earthquake risk reduction in the region.

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Earthquake Hazard Mitigation for South Asia

Recommendations of Workshop in Rice University

The earthquakes of the past several years have demonstrated clearly the enormous threat earthquakes pose to developing countries' economic and societal well being. It is generally acknowledged that the region at greatest risk of earthquakes lies along the boundary of the Eurasian and Indian tectonic plates. The countries along the Himalayan arc may suffer enormous damage from earthquakes in the future. Despite this general understanding, four crucial components of risk reduction in this geographical area are missing:

- Regional alliances for developing a collaborative approach to shared risk
- Reliable regional (multi-country) hazard maps based on systematic scientific studies
- Application of appropriate engineering knowledge in codes, construction training, inspection, and retrofitting programs
- Public policy frameworks and mobilization strategies to educate, train, and empower citizens and agencies that can (a) reduce risk and (b) respond when earthquakes occur.

The absence of these crucial elements contributed to the cumulative death toll of hundreds of thousands in the earthquakes in Gujarat, India in 2001, in Kashmir in 2005, and in Indonesia in 2006 and 2007. Further, the deaths are only part of the long-term suffering of orphans and families, economic hardship, and the danger of increased social and political instability. Some of this distress was needless, caused by ignorance about the impending danger and about how to make structures resilient to seismic events. Some activity was wasteful, the product of uncoordinated overlapping relief efforts that squandered aid and delayed help to those trapped in rubble or exposed to cold and rain.

The world has taken note of these problems and formed broad strategies for action. Earthquake hazard mitigation is among the aims of The United Nations International Strategy for Disaster Reduction's 2007 Hyogo Framework, the ProVention Forum Framework for Making Disaster Risk Reduction Work (forum was held in Dar es Salaam, Tanzania in 2007), and other recently adopted frameworks. Yet governments of developing nations are far from achieving crucial risk reduction requirements. In some cases the immediate objectives of governments and leaders appear to conflict with the long-term goals of risk reduction, resulting in superficial, ineffective gestures of reform.

Indeed, Dr. R.K. Bhandari bluntly pointed to the missing first step in his keynote address to the India Disaster Management Congress in New Delhi in November 2006. Although he was speaking of India, his words are applicable to the whole region:

<u>There is not even a single case of landslide study in India to date, which can be called scientific, systematic and comprehensive.</u> In a great majority of cases, there is hardly any connection between the report of a landslide investigation and engineering design of control works.

For a landslide study to be scientific, it is important to go significantly beyond mapping geology and naming probable causative factors and design control measures merely based on the so called past experience. . . .

For a study to be systematic, choice of equipment, types of tests and test procedures must be judicious.

And for landslide study to be comprehensive, it must necessarily trace the landslide history of the slope and relate the investigations and analyses to the demands of current and the future land uses. Modernization of the tools and techniques of landslide investigation and creating a pool of trained professionals are most essential. . . . Remote sensing devices for study of rapid motion landslides and their run-out effects also need to be introduced.

Participants in an interdisciplinary workshop on July 29-30, 2007 in Houston, Texas explored the ways that governments may implement the various general frameworks for earthquake risk reduction. The following summary of the workshop participants' consensus stresses the need for collaboration, coordination, and commitment to regional resiliency with the kind of candor and integrity demonstrated in Dr. Bandhari's address.

The potential loss of life, livelihoods, and communities surely must outweigh interests of national prestige or political posturing. This document discusses forcefully governments' responsibilities for comprehensive preparedness and rapid response and proposes the diversification of risk that can be gained through mutual aid agreements.

Consideration of Earthquake Issues Related to the Hyogo Framework

The United Nations International Strategy for Disaster Reduction's "Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters" has three strategic goals: (1) the integration of disaster risk reduction into sustainable development policies and planning; (2) development and strengthening of institutions, mechanisms, and capacities to build resilience to hazards, and (3) the systematic incorporation of risk reduction approaches into the implementation of emergency preparedness, response, and recovery programs. It proposes five priorities for action:

(1) Ensure that disaster risk reduction is a national and a local priority with a strong institutional basis for implementation.

(2) Identify, assess, and monitor disaster risks and enhance early warning.

(3) Use knowledge, innovation and education to build a culture of safety and resilience at all levels.

(4) Reduce the underlying risk factors.

(5) Strengthen disaster preparedness for effective response at all levels.

Conference participants had no doubt that these goals and priorities are excellent. However, the Hyogo Framework attempts to cover all disasters, and while integration of plans for many types of disasters is an ultimate goal, the specific nature of earthquake risks (collapse of structures, loss of transportation and other infrastructure, lack of forecasting) justifies a special consideration of actions that relate to earthquakes in particular. The distribution of earthquake risk across national borders especially prompted the participants to recommend a collaborative, regional approach to risk identification, risk reduction, and staged response in which local and nearby communities and nations plan for swift, effective response during the hours immediately following an earthquake. In addition, participants felt that a plan, formulated well in advance, was necessary to receive and distribute coordinated, culturally appropriate aid from external sources in the second stage of response. Finally, recognizing the limited financial resources of developing countries, participants saw the benefit of securing a large grant for launching a regional collaboration to undertake the research, planning, and coordination that must exist even though the time of the next earthquake cannot be predicted precisely.

The recommendations presented here should be seen as a focused approach to be undertaken as part of the broader efforts in implementing the Hyogo Framework's plans. Ultimately, the participants hope that the earthquake risk reduction strategies recommended here can become a model for efficiently and cost-effectively implementing the Hyogo Framework's disaster reduction goals.

Principles for the Workshop's Earthquake Risk Reduction Recommendations

- Base community resilience on (1) construction and maintenance of infrastructures and structures (which put people at risk) and (2) people and organizations
- Favor local or community-based solutions to deal with needs immediately after an earthquake
- Build a culture of risk reduction
- Empower people by imparting knowledge through culturally appropriate materials so that communities can contribute to their own safety and social stability
- Plan for the NEXT disaster, not the last one
- Plan to use response periods to motivate change in readiness
- Coordinate response plans for different types of hazards

Six Basic Recommendations for Earthquake Risk Reduction

1. Form a consortium of governments to collaborate in earthquake risk reduction as well as relief efforts since risk is distributed across national boundaries.
2. Identify and share information about hazards based on systematic seismic studies.
3. Assess individual and community vulnerabilities and capacities.
4. Educate communities in risk reduction, practices, and methods.
5. Involve all stakeholders to ensure risk avoidance, self-rescue, mutual aid, and synergy and resilience in the risk reduction system.
6. Seek external grants to fund upfront costs of research and implementation of collaboration.

Methods Recommended for HF Implementation of Earthquake Risk Reduction

HF 1: Ensure that disaster risk reduction is a national and a local priority with a strong institutional basis for implementation.

- Create an agency or council to guide collaboration across national and state boundaries through a consortium of governments.
- Develop a multi-jurisdictional legal and policy framework for responding to disasters and for development as well as reconstruction in expanding urban areas.
- Create multiple building codes suited to the available building materials and hazard level of the area and link these to assistance and motivating incentives for compliance and maintenance.
- Enforce these codes in engineered new construction and through networks of collaborating families who can mentor people laboring to construct dwellings, shops, and schools.
- Give schools and other critical infrastructure (such as hospitals and communication sources) top priority for safe construction and code compliance.
- Prepare damage assessment models and regional economic models that can enable groups to evaluate both the direct and indirect economic impacts of earthquakes.
- Support the launch of regional studies and planning with a grant from outside the participating countries.
- Re-imagine and restructure government capacities at several levels:
    - o Expand capacity to receive, process, and transmit aid to affected areas.
    - o Strengthen newly created emergency management units by linking them to the technical support agency, the appropriate intellectual communities, NGOs, and agencies with other critical infrastructure responsibilities.
    - o Expand the scope of centers and agencies responsible for research.
    - o Work with social scientists and NGOs to address the cultural complexity of populations at risk, addressing the possible confusions resulting from the use of multiple languages, reliance on oral communication, and low literacy levels.

HF 2: Identify, assess, and monitor disaster risks and enhance early warning.

- Ensure that governments receive reliable, systematic guidance by bringing together an advisory team of scientists, engineers, and social scientists. They should produce hazard maps that are freely available to all stakeholders, including all relief organizations. These maps should establish where the future earthquakes might be. The advisory team could also monitor sites.
- Create intellectual communities of scholars and practitioners across national borders and institutions. They must be able to conduct research without fear of political reprisal or control in order to provide reliable information.

- Revise building codes and assume that such codes will be continuously modified as new research on earthquake risk is produced.
- Develop reliable and redundant emergency communication systems.

HF 3: Use knowledge, innovation and education to build a culture of safety and resilience at all levels.

- Using guides such as the ProVention Consortium's *Making Disaster Risk Reduction Work* and the UN USDR's *Words Into Action: A Guide for Implementing the Hyogo Framework,* foster community-based preparedness.
- Include non-governmental organizations in the planning process to avoid duplication and waste or delays in response in the precious hours immediately following a disaster.
- Include women, youth, and other vulnerable groups in planning so that their needs will be anticipated and met and so that their potential for contributing to resilience and survival will be realized.
- Provide assistance from the technical advisory committee to those who prepare materials (including radio dramas and other novel formats) to explain scientifically the characteristics of the built environment as well as the characteristics of the natural environment (e.g. landslide possibilities, soil stability, and so on). Materials should be culturally appropriate, highly visual, prepared for audiences with different literacy levels and technical knowledge.

HF4: Reduce the underlying risk factors.

- Revise building codes and assume that such codes will be continuously modified as new research on earthquake risk is produced (as mentioned in the recommended for changes in government organization).
- Create multiple building codes suited to the available building materials and hazard level of the area and link these to assistance and motivating incentives for compliance and maintenance.
- Enforce these codes in engineered new construction and through networks of collaborating families who can mentor people laboring to construct dwellings, shops, and schools.
- Give schools and other critical infrastructure (such as hospitals and communication sources) top priority for safe construction and compliance with building codes.
- Teach groups in local communities how to build more resilient structures using local materials or materials supplied to them at low or no cost (such as beams and key structural elements that increase a building's earthquake resilience).
- Consider using women or youth as peer teachers for people in other communities or people who live outside of official villages.

HF5: Strengthen disaster preparedness for effective response at all levels.

- Develop a reconstruction framework well in advance to ensure that disaster response furthers development goals and contributes to the long-term vitality of cultures and economies.

- Also develop area, national, and regional cooperative plans for sharing resources and personnel in times of disaster.
- Form and fund an alliance of countries that share comparable levels of risk. In most years, only one or two of the countries will experience an earthquake. Funds can be used for risk reduction programs across the region.
- Collaborate with universities to expand the kind of cooperation fostered by the Consortium of Universities for Research in Earthquake Engineering (CUREE) [www.unisdr.org/wdrc-2006-2007 Madras University]. CUREE is a non-profit organization devoted to the advancement of earthquake engineering research, education and implementation. Such a consortium should ensure the development of professionals, including emergency managers, teachers, community capacity-builders, and women's outreach disaster preparedness projects.

The participants in the Rice University conference look forward to the benefits of assisting with the implementation of these recommendations at their home institutions, in partnerships with colleagues abroad, and in conference presentations and funded projects.

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Devastating Earthquakes of South Asia

SAARC Disaster Management Centre, New Delhi

Introduction

South Asia has emerged as hot spot of devastating earthquakes due to both intra-plate and inter-plate seismicity particularly in the Himalayan-Hindukush region that has a very high frequency of devastating earthquakes (Table - I). These earthquakes have affected the whole of the region which directly involves six of the SAARC countries namely Afghanistan, Pakistan, India, Nepal, Bhutan and Bangladesh. In a span of 53 years between 1897 and 1950 five such deadliest earthquakes have taken place which include- Assam, 1897; Kangra, 1905; Nepal Bihar, 1934; Quetta, 1935; Assam, 1950.These earthquakes account for a loss of about 70,000 human lives, besides damage to property and infrastructure. In the present paper an attempt is made to bring back the memories of these natural calamities so as to create awareness about this impending disaster and to draw lessons learned from such events.

Assam Earthquake of 1897

This earthquake occurred on June 12, 1897 (M 8.7) with epicenter at 26.00 N, 91.00 E and it is considered as the most powerful intraplate earthquakes in the Indian sub-continent. Close to 1,500 people were killed in Assam, Meghalaya and adjoining parts of the Bengal. It has caused severe damage in an area of about 500 km radius. The earthquake caused extensive surface deformation in the affected region. There were clear instances of up throw of objects caused by the severe ground shaking which implied that the maximum vertical acceleration during the earthquake exceeded 1.0 g. The earthquake caused extensive liquefaction in the alluvial plains of Brahmaputra that in combination with ground shaking caused extensive damage to buildings, rail tracks and bridges.

The area around Shillong consisted of three types of buildings (Jain, 1998): stone buildings; ekra-built buildings consisting of wooden framework with walls of grass covered in plaster; and the timber plank buildings built on "log hut" principle, having a wooden framework covered with planks, and resting unattached to the ground. All stone buildings were leveled to ground. About half of the ekra-type buildings were also leveled to the ground, particularly due to the stone chimneys (stone or brick chimneys projecting out of the buildings were easily damaged in earthquakes). The plank buildings were in general undamaged. Damage caused by this earthquake led to the development and adoption of similar suitable resistant houses with the active initiative of the Assam government and with the help of Chinese carpenters and craftsman. Subsequently, these houses became prevalent in the north-eastern states and have shown better performance in the subsequent earthquakes. Unfortunately this type of housing known as the Assam-type housing is now being discouraged to save possibly timber that is becoming scarce now. The timber could be replaced by alternate materials while maintaining the earthquake-resistant features of these houses. Presently the constructions in the area are based on poorly-built reinforced concrete or brick masonry which is highly susceptible to earthquake damages in future.

Kangra Earthquake of 1905

The Kangra earthquake of 1905 is one of the great earthquakes of the Himalayan–Hindukush belt having a magnitude of 8.0. It was one of the deadliest as it took a heavy toll of human lives about a century ago in a sparsely populated hilly terrain. Damage to buildings is one of the most important criteria to assess the devastating effect of an earthquake. According to the description of Middlemiss (1910), the houses had become mere heaps of sun-dried bricks mingled with slates and rafters in one of the epicentral areas around Dharamshala. McLeoganj bazaar situated on a very narrow portion of the ridge forming a low saddle surrounded on both sides by steep slopes was completely leveled to the ground with no building standing, even partially, thereby highlighting the topographic influence on amplified ground motion.

The severity of earthquake was so high that civil and military staff were reduced to half in Dharmsala, and other places near the focus of the earthquake. This earthquake took a toll of 20,000 human lives and leveled to ground about 100,000 houses. The high casualty is mainly due to the fact that the earthquake took place early in the morning when most people were in bed or at least indoors. The shocks were so intense in the epicentral area that as people tried to run out of their houses they were thrown to the ground and at the same time houses collapsed on them. There are many such reports from the Dharamshala cantonment in the epicentral area. There were reports indicating that the people must have rushed towards the doors and were thrown back by the surface waves, and then buried as the walls and roofs fell in. There were hardly any cases of people being killed on their beds. Interestingly, Kangra earthquake was considered to have a second epicenter around Dehradun, which was also severely damaged along with some buildings in Mussoorie Hill Station.

Although most of the buildings were completely destroyed, some survived due to better construction and foundation. For example, a heavy iron girder bridge in the area remained undamaged. This indicates that well built engineered structures survived the severest jolt of the quake. This fact is brought out clearly by a report in The Pioneer of 26th April, "from Pathankot to Dharmsala there are hundreds of bridges, large and small, and only one was wrecked- some with fine stone arches and others with iron girders all remaining intact". This statement is indicative of the fact that the type and quality of construction play an important role in risk reduction due to earthquakes

Bihar - Nepal Earthquake of 1934

This 8.4 magnitude earthquake occurred on January 15, 1934 at around 2:13 pm and caused wide-spread damage in India (northern Bihar) and Nepal killing around 7,253 in India and 3,400 in Nepal, which is less compared to Kangra event as most people were outdoors in the winter afternoon.

The epicentre for this event was located at 26.500 N, 86.500 E in the eastern Nepal about 240 km away from Kathmandu valley but it experienced intensities of IX-X in the Modified Mercalli scale.

The majority of the reported destruction from the earthquake occurred in Kathmandu valley and along the eastern Terai plains bordering northern India. More than 80,000 houses were damaged in Nepal out of which 12,397 houses were totally destroyed in Kathmandu valley. It is estimated that around seventy percent of the houses in the valley were affected which confirmed that Kathmandu valley is susceptible to enhanced ground motion during an earthquake event mainly due to its geological characteristics (http://www.jica-eqdm-ktm.org.np/ earthquakedamage/ bihar_nepal.htm).

Source mechanism of the Bihar-Nepal earthquake suggests that high tectonic stresses are prevailing in this region. A major part of the stresses accumulated before the occurrence of the earthquake had been released through the main shock. An investigation of temporal and spatial variation of regional seismicity reveals presence of seismic gaps before the occurrence of the major event (Singh and Gupta, 1980).

Heavy damage occurred in the towns of Muzaffarpur, Motihari, Dharbhanga, and Munger (Monghyr). The earthquake caused maximum intensity of X in 125 km long and 30 km wide area. Besides, two distant areas located about 160 km from the main damage area also experienced intensity of X; these were Kathmandu valley in the north and Munger in the south mainly due to underlying geological and soil conditions of that region. Most of the buildings tilted and slumped bodily into the ground in an area of about 300 km long known as the "slump belt" that experienced extensive liquefaction which was manifested by ground fracturing, emission of sand and water and formation of sand boils. One of the fissures was 4.5 m deep, 9 m wide, 270 m long. At places, 2.0 m high embankments leveled to ground mainly due to lateral spread. The depth of lakes, ponds, and other depressions became shallower due to partial filling from bunds due to lateral spreading as well.

Houses and structures tumbled and became rubble in large tracts of affected region. Thousands died in both Nepal and northern India and many were left injured and homeless. Monghyr area was worst affected town in Bihar, with maximum damage to buildings and structures (Dunn et al, 1939). It lies in the southern edge of the Indo-Gangetic plains with outcrops of the Archaen rocks. It was observed that buildings and structures on the rock outcrops were less damaged than those on the alluvium, where lower shear wave velocity and higher spectral amplification caused maximum damage to built environment. It is a matter of great concern that if a similar earthquake strikes today the death toll would be much higher mainly due to higher population growth coupled with low quality construction of houses.

Quetta Earthquake of 1935

Quetta Earthquake which occurred on May 31st, 1935, may be accounted as the most disastrous earthquake due to the large number of lives lost. This earthquake had created havoc in Quetta and its surrounding areas nearly 72 years ago and it was such a calamity that even today the magnitude and horrifying effects are still remembered. Although shock was felt over a comparatively small area, the intensity within the epicentral area was very high causing maximum death and destruction. The recent earthquake that shook the northern areas of Pakistan and India in October 2005 brought back painful memories of the earlier disaster.

In early hours of May 31, 1935, Quetta city with a population of about fifty thousand was turned into a valley of death within a short span of 45 seconds claiming around thirty-five thousand lives. A part of Quetta Cantonment was completely damaged but the loss of life and property was comparatively less. Royal Air Force lines which were in low lying ground along the Samungly Road, north of Quetta suffered more and over 50 percent of their effective strength either perished or injured. The violent tremor was felt strongly in the villages around Quetta and the neighbouring district of Kalat. The death toll as reported was 3500 in the rural areas of the Quetta district and almost an equal number in the district of Kalat. The Quetta earthquake of 1935 was quite different from the Bihar earthquake of 1934, the devastating effect was felt over a much smaller and less thickly populated area.

The earthquake occurred at 3.03am and some people who survived the earthquake were reported to be alert due to tremors on various dates before the main shock. This phenomenon was not unusual in Quetta where mild tremors were frequently felt throughout the year and, therefore, no particular attention was paid. Majority of the people were sleeping inside their houses and this was one of the main reasons for greater loss to human life. According to investigations conducted after the catastrophe, it appeared that almost all buildings in Quetta city and civil lines collapsed within 45 seconds of the first shock. A number of aftershocks jolted the city within few hours of the main shock and on subsequent days, but no further damage was caused probably because of the fact that no building was intact and left standing in Quetta town.

The communication between Quetta and other parts of the country was confined to only one railway line through Bolan Pass which made the evacuation and supply work extremely difficult. The electric supply in Quetta was cut off because the power station was damaged by the earthquake. The presence of a large army garrison in Quetta proved to be advantageous because the entire military resources were immediately mobilized to assist in rescue work, as well as other relief measures. Units of the army moved into city immediately after the earthquake and areas were allocated to various groups to conduct rescue operations under the direct supervision of the then General Officer Commanding of Quetta Garrison (www.dawn.com/weekly/dmag/archieve).

The only thing which remained intact and undamaged was the 14-mile pipe line which supplies water to Quetta city and the cantonment. The army authorities immediately assumed control of this vital line and every effort was made to maintain water supply throughout the critical period. According to official statistics, medical treatment was provided to twenty to twenty five thousand people by June 14, 1935, in various civil and military hospitals and dispensaries. It may be mentioned that the subordinate civil officials and Quetta police force were practically wiped out. The most pressing need was to rescue people buried under the debris and give them proper medical assistance, food and shelter.

One of the major steps that were taken to cope with the situation was to restrict the entry of people from outside into Quetta. This was necessitated because of the shortage of food supplies in the city. The ration at the disposal of the military was limited. The survivors were shifted to various camps setup in the city. The total population of the town shifted to these camps numbered 15,621 by the end of the year 1935. The Viceroy's Quetta Relief Fund started on June 3, 1935, and contributions continued to pour in until a total of five million rupees were collected. The actual work of distribution of relief was mainly carried out by the local organisations. There was hardly any family in Quetta which had not lost one or more of their members in the great earthquake.

Based on damages to built environment, the maximum intensity of 10 was assigned to parts of the epicentral area where complete devastation had occurred. However, it is important to note that, good quality of built environment can withstand the disastrous effect to a great extent. In Quetta, new railway quarters, constructed on earthquake-proof lines, withstood the shock remarkably well. Although situated in the most damaged part of Quetta, they survived with minimum amount of movement at the ends of the joints.

Some of the residents of Quetta town had reportedly noticed the birds and animals being in state of unusual excitement before the earthquake, which served as prior warning about something unusual about to happen. Secondly the observation of foreshocks could have provided clues to the impending danger.

Assam Earthquake of 1950

One of the biggest earthquakes of the region was recorded at about 7-40 p.m. (Indian Standard time) on the 15th August, 1950. It caused widespread devastation throughout the Upper Assam, particularly in the frontier tribal districts of the Mishmi and Abor hills and parts of the Lakhimpur and Sibsagar districts. The epicentre was located at the India-Burma-China border (28.70N 96.60E). The instrumental magnitude could not be calculated from the records of any of the Indian observatories. The instrumental magnitude has, however, been calculated by the seismologists of the United States of America, who considered the present earthquake to be one of the five biggest in human history and the magnitude of the earthquake was assigned between 8.25 to 8.5. A preliminary examination of the seismograms of the Indian Observatories calculated by the Meteorological Department indicates a probable depth of focus not more than 50 km from the surface of the earth.

The earthquake shock lasted for a period ranging from 4 minutes to 8 minutes within the severely affected area. It is not known how far this was felt on the Tibetan side, but news from other side of the McMahon Line shows that extensive damage has occurred in the hills and heavy casualties took place among the hill tribes bordering the North-East Frontier. The shock was also felt throughout Eastern India. It was reported that the quake was accompanied by a rumbling or booming sound appearing to come from different directions in different localities. Usually these sounds are produced by rapid vibrations of the ground transmitted to the layer of air in contact with it. In some cases they may be accounted for by landslips in the hills. Besides this there were hissing sounds, where sands and water were ejected through fissures. These were very common close to rivers where shallow water table exists. Vibration was so intense that most people had difficulty in standing. They were compelled either to sit or lie down on the ground.

As the affected area was sparsely populated, and the earthquake occurred just after nightfall when most of the people were awake, the loss of life has been less in comparison with the magnitude of the shock. A total number of 1,526 deaths have been reported. The main shock was followed by a large number of after-shocks throughout the night at very short intervals. Some of the after-shocks have been fairly strong particularly those of 16th to 18th August, 13th and 30th September and 4th October 1950.

It was observed that destruction has been caused over a wide area ranging from 250 to 300 Km from epicentre, and the main shock was recorded by seismographs all over the world. In the high intensity areas due to liquefaction, the ground cracked and fissured, coarse grey sand and silt, together with water, spouted from vents during the earthquake over a large area. The sand-vents were confined to areas close to rivers underlain by shallow water table.

Brahmaputra river was in a great commotion during the earthquake. According to eye witnesses roaring waves of about 4 feet high were observed. Considerable changes had taken place in the navigable channels of the Brahmaputra due to the movement of sand. At many places, it has been observed that channels of the Brahmaputra have been silted up due to the squeezing out and fissuring of the soft banks on account of lateral spreading adjacent to the river bluffs.

Several tributaries of Brahmaputra River were blocked by landslips caused by the violent shaking of the earthquake. Subansiri river dried up after the shock on account of the seismicity induced landslide across the river. The dam burst on the night of 19th August and inundated about 500 square kilometers causing additional damages and casualties. The Subansiri and its other tributaries, left their old channels at many places and cut new ones, thus causing heavy destruction of some villages, tea gardens and other cultivated lands.

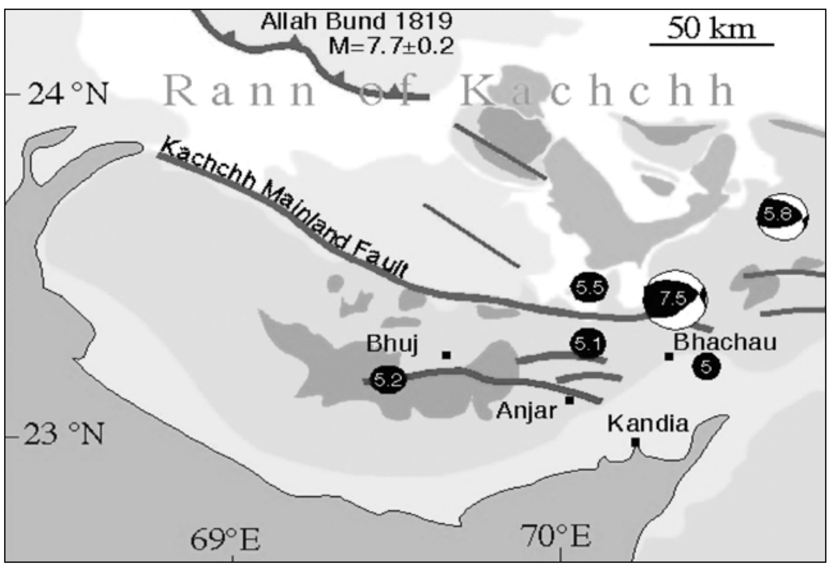
Brick-masonry buildings were not very common in Upper Assam. The common type of houses include: a) semi-pucca buildings of which the lower three to four feet from the plinth are brick masonry and the upper portion is of split bamboo or *ekra* covered with mud or sand-and-lime plaster, usually supporting G. I. sheet roof; b) structures supported on a wooden frame-work, *i.e.* with wooden posts driven into a brick masonry plinth or directly in alluvial foundations. The frame-work is generally filled in with *ekra* with mud plaster, usually supporting a light roof of grass or G. I. sheet; c) third type is similar to (a) and (b), but with frame-work merely resting on the plinth. These are comparatively light and were much less damaged than pucca buildings. Buildings at Dibrugarh and Tinsukia have been damaged by shaking rather than slumping. It has been reported at many cases that buildings had suffered mostly due to poor quality of the material and construction. The collapsed houses were fairly old tall structures, with poor quality lime-and-sand mortar. Considerable damages also occurred in Tea Estates, due to collapse of Teahouses, quarters etc.

Following the earthquake almost all rail communications of Assam Railways were suspended. Considerable damage was seen on railway-bridges and tracks at numerous places. In many places the embankment subsided or sank down completely, leaving the lines hanging, whereas in some places the track was thrown out of alignment. Upper Assam Trunk Road was damaged at several places. Most of the bridges were damaged due to cracks and fissures or tilting of piers. Many bridges were destroyed and river beds silted up mainly due to liquefaction effect (Poddar, 1950).

In this event one important lesson was learnt that apart from ground shaking, the secondary effects such as liquefaction and landsliding can create havoc due to devastating effects in low lying areas as well as hilly areas, respectively; therefore, such effects need to be considered for comprehensive seismic hazard assessment. Based on damage pattern of different types of houses, it is recommended that the house construction in this high seismic zone need to be carried out by suitably incorporating time tested indigenous expertise in earthquake resistant house construction. The same may be brought to practice after suitably blending with the modern construction methods and materials.

Bhuj Earthquake of 2001

A major earthquake (USGS: 01/01/26 03:16:41 UTC 23.36N 70.34E Depth 22 km 7.7 Ms) occurred in Gujarat, India about 65 miles (110 km) north-northeast of Jamnagar, India or about 180 miles (290 km) southeast of Hyderabad. A preliminary magnitude of 7.9 was computed for this earthquake, which was later routinely downgraded to 7.7. The earthquake occurred along an approximately East-West trending thrust fault at shallow (less than 25 kilometers) depth (Figure 1). The strain that caused this earthquake is possibly due to the Indian plate pushing northward into the Eurasian plate.

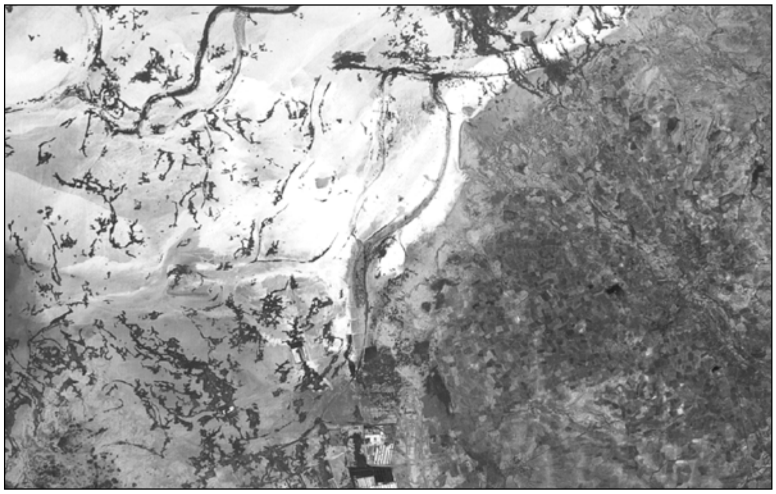


Map showing the epicentre of 26.1.2001 earthquake along with major faults
(Data source : http://cires.colorado.edu/~bilham/India.html)

The affected area lies in the western India between latitude 23 to 24 degree North and longitude 69 to 71degree east. Tectonic geomorphology indicates that the Kachchh region may lie within a transition zone between the stable continental interior of Peninsular India and the active plate margin. According to Biswas and Deshpande (1970) and Malik et al.(2000), this area consists of a series of folds and faults with a general WNW/ ESE trend. The principal faults in the region are the east-west trending Katrol Hills fault, Kachchh Mainland fault, Island Belt fault and the Allah Bund fault, which was the source of the 1819 Kachchh earthquake of M 7.8 (Figure 1). The location of the epicentre and devastation indicate that the Kachchh Mainland fault, or a part of it, possibly got reactivated on 26th January 2001. However, based on the analysis of aftershocks and due to lack of surfacial expression of fault, it was suggested that the responsible fault may be a blind fault i.e. not exposed on the surface, as it happened during Alha Bund earthquake of 1819, which remained few hundred meters below the ground unexposed (Bilham, 2001). The current rupture zone consisting of minor cracks on surface appears to lie on the southern edge of the Rann of Kachchh, north of Bhuj and Bhachau. The Kachchh Mainland fault is a vertical steeply inclined normal fault, but changes upward into high angle reverse fault. Overall this region has characteristics of both intraplate and plate margin environments. The presence of an active fold and thrust belt suggests that this region is part of the diffuse Indian/Asia plate boundary, or at least a transition zone between the stable portion of peninsular India and the plate boundary. With the presence of faults and rift zones, this area can be classified as "Rifted Stable Continental Region (SCR) extended crust", a unique setting for seismological investigations (Rajendran, 2000).

This region has experienced high levels of seismic activity throughout the past 200 years. The seismic data of Kachchh from various sources such as (i) the Indian Meteorological Department (IMD), New-Delhi, India, (ii) National Earthquake Information Center, United States Geological Survey (USGS) incorporating the available information from Gujarat Kachchh District Gazetteer, and (iii) published literature indicate that the area had experienced several earthquakes, magnitude ranging from 4 to 8 and intensities between III and X+(MM) (Quittmeyer and Jacob, 1979; Johnston and Kanter, 1990; and Gowd et al. 1996). Amongst all, the 1819 earthquake of 19th century is well documented (Bilham, 1999). This event occurred on 16th June 1819 in the northwestern part of the Great Rann of Kachchh (Lat. 240 00'N; Long. 700 00'E), with a magnitude of 7.8 (Johnston and Kanter, 1990) and reached a maximum intensity of IX to X+ (MM) (Quittmeyer and Jacob, 1979). According to Oldham (1883), Oldham (1926), and Malik et al.(2000) this earthquake resulted in the formation of 6 to 9 m high alluvial scarp trending approximately E-W for about 80 to 90 km. This uplifted feature blocked the southeast flowing tributary of Indus river that was feeding fresh water in the Kachchh areas. Later, this uplifted feature was named by local peoples as "Allah Bund"- the Mound of God. Hence, this event in the seismological literature is well known as Allah Bund event of 1819. This is the only well documented evidence of recent deformation from Kachchh other than the 1956 Anjar earthquake of M 6.1. Vertical deformation in 1819 reached 6m and in 1956, 1m. It is most likely that surface displacements may exceed 5m in 2001 earthquake (http://cires.colorado.edu/~bilham).

Wide spread liquefaction and associated phenomenon were reported by various news agencies, hydrologists and by local villagers, with an indication that the flow was sufficient in some cases to activate desert rivers that have been dry for more than a century. The satellite data showed wide spread saline fluid intrusion in Rann of Kachchh, particularly in the eastern side of Pachham island, south west of Khadir island, north west of Chobari and north of Dudha. It is also reported by Times of India that areas in the Banni region, water has been sighted almost at ground level, which has astonished the locals. The Ground Water Board has also reported extensive damage to pipelines, particularly those running across the Rann of Kachchh where extensive liquefaction was observed. In the epicentral area between Chobari and Bachau, many water pipes and wells were broken, some due to lateral spreading with displacement ranging up to 1.3m. This fact points towards the fact that the Rann of Kachchh have suffered deformation due to lateral spreading associated with liquefaction in 1819 and 2001 earthquakes. Mud-volcanoes and sand blows of various dimensions have been reported in Rann of Kachchh. The fresh flow of saline fluid has taken course of ancient channels giving an indication of reappearance of rivers. However, satellite images indicate that these streams only run for short distances



Satellite image showing extensive liquefaction in Rann of Kachchh

Satellite data showed intrusion of saline fluid in many parts of the Little Rann and Gulf of Kachchh, particularly in two coastal areas around south and south east of Kandla region. The port of Kandla was severely damaged by liquefaction processes. In Kandla port area it was reported that liquefaction sand boils/discharges randomly distributed throughout the port premises. The port signal tower building, gate office structure, and IOC storage tanks have tilted and settled due to liquefaction effect. Apart from this many areas covered by recent, Holocene deposits and mud flats also show water intrusion. It is interesting to observe a linear scarp of 50 cm high, striking east-west for about 300 meters in the farm fields with very gentle slope towards north. It is further reported that about 100m south of the scarp, the ground is fractured by extensional faults, which suggests probable effect of lateral spread due to liquefaction.

Massive surface deformations in the form of cracks are reported from many parts of the region. Uplift in the 1819 event created an 80-km-long natural dam (the Allah Bund or Dam of God) across the eastern most branch of the Indus River. A lake was formed south of the Allah Bund that remains a depression (Lake Sindri) that is flooded during the summer monsoons. It is possible that similar processes have occurred in the current earthquake. However, no major fault of recent origin could be identified, except for few cracks and liquefaction as mentioned earlier. This may be due to the blind nature of the associated fault, however few landslides (reported by Prof. T.K. Biswal, IIT Bombay) and surface deformation closure to Kachchh Mainland fault does indicate the effect of the recent phenomena. The epicenter of the Bhuj earthquake is located on the north side of the Bhachau anticline along the Kachchh Mainland fault. Satellite images reveal maximum liquid venting and surface disturbances near the southern margin of Rann of Kachchh, closure to the USGS epicentre. However, according to field investigation report by MS University, Boroda the surface deformation is more pronounced around Lodai, Rapar taluka and maximum around Amarsar, 8-10 km north of Bhachau, which is considered by them as the epicentre due to maximum destruction and deformation. However, considering the deformation of the 1819 event and the wide acceptance of the crustal shortening hypothesis, more deformation is expected than reported/detected. According to Gaur (2001), the surface deformation may extend up to 200 km from the epicentre as the slip over a large part of the rupture zone is around 4-6m.

The damage and destruction was widespread, affected area was vast and affected population was large. Twenty eight million people in Twenty-one of the total 25 districts of the state were affected in this quake that killed 13845 including 4878 school going children and injured 167,000. Around 18 towns, 181 talukas and 7633 villages in the affected districts had seen large-scale devastation (Mishra, 2004). The affected areas even spread up to 300 km from the epicenter. In the Kutch District, four major urban areas - Bhuj, Anjar, Bachau and Rapar suffered near total destruction. The rural areas in the region are also very badly affected with over 450 villages almost totally destroyed. In addition, wide spread damages also occurred in Rajkot, Jamnagar, Surendranagar, Patan and Ahmedabad districts. Other Urban areas such as Ganhidham, Morvi, Rajkot and Jamnagar have also suffered damage to major structures, infrastructure and industrial facilities. Ahmedabad the capital was also severely affected. In Ahmedabad alone, 80 buildings with 1021 flats and 82 other houses were collapsed that claimed 752 lives affecting 1103 families. In total 215,000 houses were completely collapsed and 928,000 houses were partially damaged. Additionally 9593 primary school buildings were destroyed and 42,000 school rooms were partially damaged. It is interesting to note that 3/4th of newly constructed school buildings during 1999-2000 were either destroyed or damaged. Many public buildings and historic monuments were also destroyed and damaged. Earth dams mainly constructed for irrigation purposes were damaged, requiring urgent repair. The power sector also suffered extensive damage; the total loss is estimated to be Rs. 1860 million. About 80,000 telephone lines were disrupted due to damage to 179 telephone exchanges. Transport network including road, rail net work were damaged; Surajbari bridge was severely damaged but restored in 5 weeks; in Kandla port five out of 10 dry cargo jetties developed major cracks, oil jetty was also damaged, in total 12 out of 40 small ports were damaged. The run way of Bhuj airport and old terminal building were also damaged. Agriculture and live stock assets loss was estimated to be around Rs. 5440 millions. As Gujarat is one of the industrialized states of India, 10,000 small and a number of large enterprises were affected. The total financial loss is estimated to be around Rs 100 to 150 billion and reconstruction cost is slightly higher than this figures as estimated by WB/ ADB and Gujarat Government. If the tertiary (long term effect on economy) and secondary (due to

Complete destruction of old Anjar area due to higher ground amplification and few survivors from a batch of school children who died while participating in Republic Day Parade.

loss of output of industrial activity) losses are put together, it could be around Rs 250 billion i.e. US$ 5 billion. This earthquake also caused damage and destruction in Hyderabad city of Pakistan.

As soon as the news reached about the earthquake, the Government swung into action, Union Cabinet as well as National Crisis Management Committee held urgent meetings and in a swift action, Indian Air Force was put into relief and rescue services with fleet of transport planes (48), 23,500 army troops and 3000 paramilitary forces were also put into service. Indian Navy provided three ships, two were converted into hospitals; team of doctors were flown in from different parts of India; Civil Aviation Ministry provided free air transport of relief materials; communication was restored with satellite phones, ham radios, hotlines etc.; Department of Food and Public Distribution allocated 100,000 tons of food grain and released immediately 10,000 tons of sugar, besides diesel and kerosene; Ministry of Power provided 19 large DG sets for power generation; Power Finance Corporation provided Rs 1000 million for restoration of transmission and distribution; and Rural Electrification Corporation provided similar amount on loan to Gujarat Electricity Board. Immediate assistance of Rs. 5000 million was released and additional Rs. 3300 million was provided soon after by Govt. of India; Rs 100 million was made available from PM's Relief Fund. Ministry of Rural Development made additional allocation of Rs 1500 million for constructing earthquake resistant housing for BPL families at the rate of Rs, 40,000 per dwelling unit (Gupta et al., 2002).

The state government mounted massive rescue and relief operations in association with army and paramilitary forces which involved 1152 JCBs/cranes, 543 bulldozers, 2853 dumpers, and 901 gas cutters. It deployed about 2100 technical persons, 6200 non-technical persons, 13,000 labourers, 763 specialised doctors, 1834 medical officers, and more than 2500 paramedical staff for search rescue and medical assistance. Additionally several thousand workers from NGOs and social organizations also participated in search, rescue and relief distribution. Each affected family was provided with free ration kit consisting of 50 kg of flour, three kg of rice, oil etc. Nearly 600,000 blankets, 250,000 tents and other temporary shelter materials were also provided. Over 167,000 persons were provided medical assistance.

Cash compensation was provided at the rate of Rs.100, 000 to the next kin of deceased, additional amount of Rs 50,000 was also provided in case of children, teachers, govt. employees who died while participating in Republic Day parade. Injured persons also got compensation in a graded manner maximum up to Rs. 50,000 per person. Government also distributed cash at the rate of Rs 250 per month per family and Rs. 1250 per family for household kits. In addition to government initiatives, UN agencies, NGOs/INGOs, international S&R and medical teams from 19 countries and corporate sector provided very crucial services immediately after the disaster and during rehabilitation of quake affected population. Gujarat government in collaboration with various NGOs, corporate sector and with assistance from donor organizations had initiated massive rehabilitation and reconstruction programme (involving repair of 900,000 houses, reconstruction of 200,000 houses and other critical infrastructure) which was very well executed and supported by new organizational set up such as Gujarat State Disaster Management Authority (Gupta et al., 2002; Mishra, 2004).

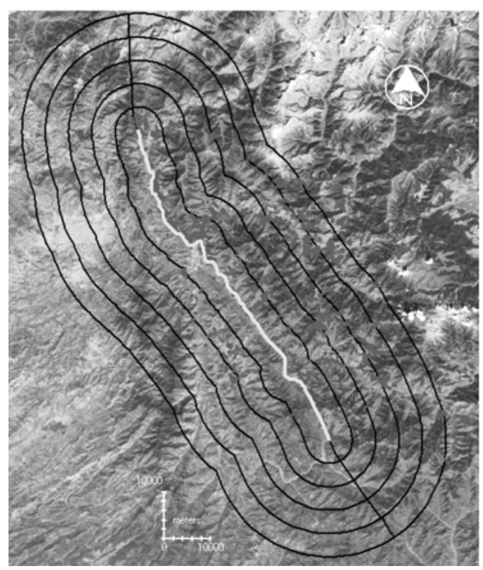
Many important lessons were learnt from this event: search and rescue capability need to be upgraded; deployment of additional seismic instruments for better data collection and analysis; earthquake specific disaster management plans are required at all levels; each district should maintain on-line inventory of resources that could be deployed in the event of disaster; the role of military and paramilitary need to well defined with respect to response plan; control rooms need to be set up/upgraded at district/taluka levels; special training is required for staff of government/ NGO on S&R, medical management, and earthquake proof construction; provision should be made to take services of retired persons from government and military forces, similar provision should also be made to engage various youth organizations; seismic engineering need to be incorporated in the syllabus of engineering courses; special training should be organized for engineers, architects and masons on safe construction in seismic hazard prone areas; the scope of insurance scheme need to be expanded and operated more comprehensively; earthquake disaster mitigation aspects need to be incorporated in development planning; funds available under ongoing development schemes can be used for mitigation and preparedness activity (Mishra, 2004).

Kashmir Earthquake of 8 October 2005

A devastating earthquake hit large parts of Pakistan and India on 8 October, 2005. The earthquake affected 5 districts of Azad Jammu & Kashmir and 5 of North West Frontier Province of Pakistan killing 73, 338, ijuring 128,309 and affecting 3.5 million people. It also affected large areas Baramulla, Kupwara and Poonch district of Jammu & Kashmir state in India, resulting loss of lives of ~ 1300 people. It was the deadliest earthquake in the history of Indian subcontinent in terms of loss of lives and property. The earthquake had magnitude Mw 7.6 and focal depth of 26 km. Its epicenter was located at 34.493 N, 73.629 E in the Indus Kohistan Seismic Zone (IKSZ) at distances of 105 km NNE of Islamabad and 125 km WNW of Srinagar. The main shock and epicentral area of aftershocks lie south of the Higher Himalaya and Pir Panjal range, WNW of Kashmir valley closure. The area suffered 23 aftershocks of magnitude > 5 and 1 aftershock of magnitude 6.2 recorded on the same day, 8 October, of the earthquake (USGS NEIC WDCS-D). The aftershocks define a linear belt which corresponds to NW-SE trending Balakot-Bagh fault, an active fault (Yeats et al. 2006) which was mapped by earlier workers (Nakata et al. 1991). The fault plane solution indicates 90 x 50 km wide plane striking N27W and dipping 35 degree. The estimated mean slip along the fault is roughly 2m calculated on the assumption Mw 7.6 and rupture dimension of 100 km x 50 km (http:// cires. Colorado.edu/~Bilham/Kashmir%20 2005 htm).

The causative fault and associated ground deformation has been mapped in the epicentral area from the sub-pixel correlation of ASTER images (Avouac et al., 2006, Parvaiz, 2007). It revealed a linear to curvilinear discontinuity that can be traced up to a distance of 86 km from Balakot to SW of Uri. It also reveals the areas affected by massive landslides close to the causative fault. In the SE direction the fault continuity could not be directly mapped due to lack of suitable ASTER data pairs. However, towards SE the fault continues (as interpreted in single data set) in the direction of Punch which is relatively less affected compared to Uri. Therefore, the SE margin of the fault can be inferred for a distance of 8 km and it terminates at a distance of 40 km from Punch and 25 km from Uri. Based on this total length of the fault is determined as 86 km which is in agreement with previous studies. The surface expression of the causative fault is much sharper on north-south component of displacement map compared to east-west component. In general the deformation zone is limited to few hundred meters on ground for most of the portion except for the north west margin where it is more diffused due to presence of fold scarp rather than clear ground ruptures (Yeats and Hussain, 2006). Towards southeast direction, the fault runs in a more curvilinear fashion due to the influence of topography. As revealed, the topography highly influences the surface expression and the rugged topography in north west margin has resulted in curvilinear expression of the fault cutting across the Kunhar valley along the previously mapped Muzaffarabad fault (Nakata et al., 1991: Nakata and Kumahara, 2006). The geomorphic expression of this fault is subtle with break in slope and triangular facets on the western bank of a smaller stream after it crosses the Kunhar river at Balakot. Between Balakot to Muzaffarabad, the break in slope is much sharper and the lower limit of the landslides on the eastern bank of Kunhar valley almost coincides with the fault.

At the intersection of the Kishanganga (Neelam) with Jhelum, the surface expression moves in northeast direction due to low relief of the valley and this can be attributed to northeast dip of the fault. Towards further southeast in the upper Jhelum valley the fault moves in a linear fashion cutting the north eastern bank of the Jhelum for about 54 km along the previously mapped Tanda fault (Nakata et al, 1991). Here again on the eastern bank of the Jhelum, the lower limit of the landslides are marked by fault extent, thereby suggesting the direct influence of the fault on development of landslides. Overall all major landslides from Balakot to Muzaffrabad and beyond have been developed on this fault with only exception of Neelam valley. After following a linear stretch from Muzaffrabad, the fault moves in further southeast direction where as the Jhelum valley takes an east ward deviation towards Uri. Towards 9 km from the deviation point, the fault shows "v" shaped expression due to presence of a hill which is also attributed to northeast dip of the fault. At the same place, a huge Hattian Bala landslide, perhaps the largest in the region had occurred on the southeastern aspect of the hill range. Towards further southeast, although the Tanda fault appears to continue for some distance, however, the surface deformation related to 2005 event is observed only up to Nurgala village, thereby suggesting that deformation has not reached the surface or it is the southeast limit of the causative fault.



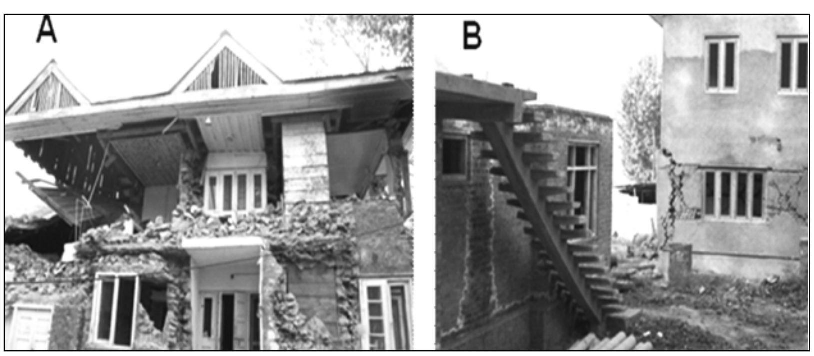
Causative fault detected by sub-pixel correlation and landslides on the hanging wall side indicate the effect of ground shaking and damages thereon (Parvaiz, 2007)

In the Jhelum valley, in eastward direction from Uri to Baramulla landslides were observed due to failure of the scarp faces of the river terraces and steep slopes in road section at around 8-10 km from Uri. Towards further east, the occurrences of the landslides are found to be more pronounced closer to Punjal Thrust and Murree Thrust. In total over 700 landslides of size larger than 45m * 45m have been mapped, out of which a large proportion of landslides have been mapped in the hanging wall side compared to footwall side. There are also numerous smaller landslides/ landslips totaling 2400 as reported by Japanese research team. At some places as mentioned before, the extent of landslides on the hill slopes is bounded by the surface expression of the causative fault.

Additionally, numerous occurrences of liquefaction and ground fracturing due to liquefaction process have been observed. Lateral spreads were observed both on gentle slopes, foot of the mountain and also at the top of the mountain and generally move toward a free face. In general these features were observed on the hanging wall side of the causative fault. Localities lying close to the active fault have suffered more damage in comparison to those away from the fault irrespective to the location of epicenter. In the Indian region, Uri lying closer to the fault is more damaged than Punch which lies in the direction of the fault at a greater distance. The liquefaction near Jammu at a long distance from the south eastern margin of the causative fault and lack of such feature in between areas shows a similarity of damage pattern as observed during Kangra earthquake of 1905, which had main epicenter around Kangra and secondary epicenter around Dehradun at a longer distance in the south east direction.

The severely affected areas include the several districts of north west and north east Pakistan, and Jammu and Kashmir, India. More than 74,000 people lost their lives out of those 18,000 were children (Source: NDMA). Most of the civil society infrastructure such as roads, schools, colleges and hospitals were destroyed and required immediate attention. It also caused large scale landslides, blockade of streams in the region affecting villages and lifeline infrastructure. The impact was felt as far as Srinagar, Jammu and Islamabad, wherein a 11-storey Margalla Towers Apartment Complex collapsed killing many people. In terms of physical damage almost 600,152 homes were destroyed – rendering 3.5 million people homeless- along with 7669 schools and colleges, and 574 health facilities (over 73% of the total), 4429 km of road (37% of total) and 30 % of telecommunication in Pakistan alone (Source: NDMA, Pakistan).

In India, although the damage was less but very significant. Maximum devastation has taken place in areas beyond Uri towards further west, due to high ground acceleration and landslides observed on colluvial wedges. In this section, some of the landslides are found to be reactivated old slides. In Uri region, particularly the township located on composite alluvial terrace system experienced maximum ground acceleration and as a result a large number of buildings were damaged. However, it was observed that buildings with good foundation and beam structure could withstand and had suffered less or negligible damage.



Variation in damages to buildings located in nearby areas shows that better quality of construction can perform much better during seismic event.

The magnitude of the devastation and overwhelming response by domestic as well as international communities, demanded harnessing and synchronisation of the national relief efforts. Govt. of Pakistan set up Federal Relief Commission (FRC) to oversee the whole operation and provide necessary guide lines for effective management of entire operation. Besides handling the enormous task of retrieving dead and injured persons and providing relief to people spread across 30,000 square km in one of the most inaccessible regions, the FRC in collaboration with many international and local NGOs carried out enormous task of reconstruction in the region in subsequent years. In total more than 129,000 injured people were evacuated from the affected region, out of which 17,000 were air lifted to nearby hospitals. The scale of relief operation was enormous as almost 950,440 tents, 6.5 million blankets, 256,400 tons of ration, 3,054 tons of medicine and compensation of Rs.22 billion was distributed among quake affected in Pakistan. Financial compensation was paid in the following manner: Rs. 100,000 per death per family, Rs 50,000 for seriously injured and Rs. 25,000 for partially injured, Rs. 175,000 per damaged house for reconstruction. Restoration and reconstruction started with a principle of Build Back Better and all critical facilities including, road, telecommunication, water supply, health care, schooling and housing are being restored/developed better than what existed before 8/10 (NDMA, 2007).

The response in Jammu and Kashmir, started with immediate search and rescue operations led by the army, air force and local volunteers from National Institute of Technology, Hazratbal and many NGOs and social organisations in Uri, Tangdhar, Baramulla and Kupwara, Srinagar, Jammu and Udhampur. The state government had opened relief centres at the Mirwaiz Manzil and Jamia Masjid. Army and Air force personnel have evacuated at least 274 persons from Baramullah, Tangdhar and Uri, the injured persons were treated at Field Hospital, SMHS hospital Srinagar, Bone and Joint Hospital Srinagar, Sher-e-Kashmir Institute and in makeshift hospitals.

In a quick response, state administration had mobilized all essential items such as tents, blankets, sleeping bags, kitchen sets, kerosene, drinking water, woollen clothes, medicines, sugar, and fresh milk. The Food Cooperation of India had also readied stock reserve of 83,000 metric tons of food grains for distribution. The water and electricity supplies had also been restored in many parts of the quake affected region.

For immediate relief work and assistance Rs 1 billion (US$ 23.25 million) and ex-gratia amount of Rs 100,000 (US$ 2325) to the next of kin of the deceased had been sanctioned from the Prime Minister's National Relief Fund. Additionally, the state government had sanctioned ex-gratia of Rs. 5000 (US $ 111) per person. The central government had announced a package of central relief of Rs.5 billion (US$ 116.27 million) for rehabilitation work. This is in addition to Rs. 142 billion (US $31.646 million) relief already sanctioned by the central government for quake affected region. State government had distributed Rs 75,000 per family in earthquake affected areas for complete reconstruction and rehabilitation.

Many lessons were learnt from this event. In Pakistan, it was realized that a disaster management body should be established to ensure speedy, unified response under "one window" arrangement. Information management facility must be established for monitoring, collation, dissemination of relevant information to all stake holders through website, setting up call centers, and giving telephone number of ground staff. Specialized search and rescue teams should be available locally than depending on foreign rescue teams which take time to arrive and lack local knowledge and experience. Proper coordination should be there to receive relief material, avoid duplication and smooth distribution. Well equipped emergency medical units should be set up at district level for quick mobilization and additional specialized medical personnel should be available to attend to emergencies. Measures must be taken to minimize loss of communication by deploying satellite communication, GSM and WLL technology. In reconstruction, there should be strict adherence to building codes, appropriate land use, quake-resistant construction particularly that applies to health, administration and education facilities (NDMA, 2007).

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Table - I: Important Devastating Earthquakes of South Asia

Year, AD	Location	Magnitude	Deaths	Affected countries
819	Afghanistan	7.4	Heavy casualties	Afghanistan
1505	Afghanistan, Kabul	7.3	Heavy casualties	Afghanistan
11 Oct. 1737	India, Calcutta	—	300,000	India,
16 June 1819	India, Kutch	8.0	1543	India,
22 Jan 1832	Afghanistan, Badakhshan	7.4	Thousands killed	Afghanistan
1833	Nepal	7.7	414	Nepal
12 June 1897	India, Assam	8.7	1500	India,
4 April 1905 15 Jan 1934	India, Kangra Nepal-India Border	8.0 8.3	20,000 10,653	India, Pakistan, Nepal India, Nepal
31 May 1935	Pakistan, Quetta	7.5	35,000	Pakistan
26 June 1941	India, Andman Islands	8.1	3000 (Aprox.)	India,
1945	Pakistan, Makran	8.0	4000	Pakistan, India
15 Aug. 1950	India, Assam	8.6	1526	India, Bangladesh
9 June 1956	Afghanistan, Kabul	7.6	400	Afghanistan
21 July 1956	India, Anjar	7.0	115	India
1974	Northern Pakistan	6.2	5,300	Pakistan
1980	Nepal	6.5	103	Nepal
20 Aug 1988	Nepal-India border	6.6	1450	India and Nepal
20 Oct 1991	India, Uttarkashi	6.6	768	India
30 Sep.1993	India, Latur	6.4	10,000	India
22 May 1997	India, Jabalpur	6.0	60	India
4 Feb. 1998	Afghanistan	6.1	2500	Afghanistan
30 May 1998	Afghanistan-Tajikistan border	6.6	4000	Afghanistan
29 Mar 1999	India, Chamoli	6.8	106	India
26 Jan. 2001	India, Bhuj	6.9	13,845	India, Pakistan
3 March 2002	Hindukush	7.4	166	Afghanistan
25 March 2002	Hindukush Region	6.1	1000	Afghanistan
5 April 2004	Hindukush	6.6	3	Afghanistan
12 Dec. 2005	Hindukush	6.5	5	Afghanistan
8 Oct. 2005	Pakistan-India	7.6	74,500(+)	Pakistan, India, Afghanistan
29 Oct. 2008	Pakistan	6.4	163	Pakistan

(Source: IMD, USGS, ISC, NOAA, ISET, CGS, GSI, ASC)

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Next year's Earthquake vs. Last year's Disaster vis-à-vis Engineered Action vs. Societal Reaction

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Abstract

An oft-neglected observation in earthquake studies is that the next earthquake will invariably not visit the region that has just been destroyed, but will strike somewhere else. A knee-jerk reaction to earthquakes - to rebuild earthquake resistant dwellings and civic structures after their destruction - though well meaning, is thus doomed to immediate failure. The next earthquake will occur elsewhere, and is likely to be as bad as the last one. In a world of increasing populations and decreasing building quality, it is almost guaranteed to be worse. As a result, societies have a choice - they must either admit to the need to impose regional earthquake resistant construction, or they must admit to their collective responsibility for future fatalities from earthquakes. I argue that one requires action in the form of a 10% increase in the cost of present-day construction, the other requires repeated reaction; it guarantees unnecessary deaths, countless injuries, and endless disaster relief efforts. Politicians have the power to do something about this. What is needed is a regional policy for earthquake resistance.

Introduction

In the past 500 years the death-toll from earthquakes has risen steadily throughout the world. The 27000/year mean fatality rate between 1900 and 2000 is double that of the previous two centuries, and the 21st century is off to an appalling start with more than half a million fatalities in its first 8 years

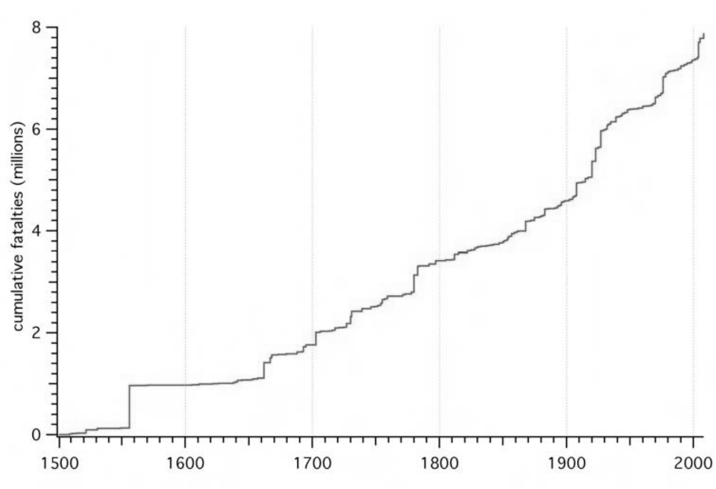

Figure 1: Deaths from earthquakes since 1500. Each step in the graph indicates the number of fatalities in an earthquake for that year.

The death-toll from earthquakes is not uniform throughout the world. Most of the disasters responsible for the statistics of Figure 1 occur near the world's boundaries, the worst affected nations being those nations in the Alpine-Himalayan collision zone - a dozen countries wedged between the vice-like convergence of the northward moving African, Arabian, Indian and Australian plates and the immobile Euro-Asian plate

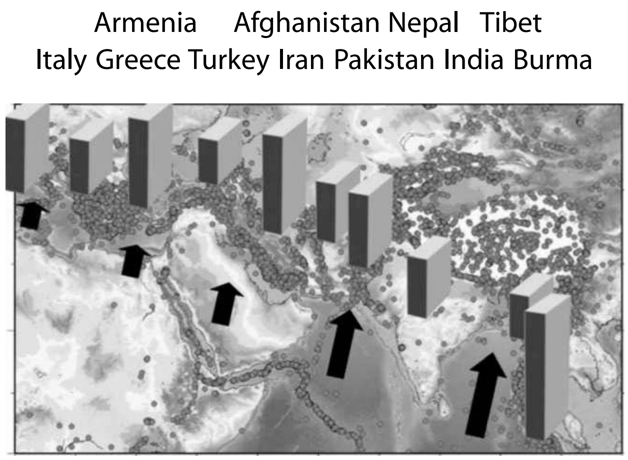

Figure 2: Deaths from earthquakes are unevenly distributed on our planet. Bars indicate cumulative deaths from earthquakes in the past 200 years. Many occur in the land area squeezed between the Asian plate in the north, and the- African, Arabian, Indian and Australian plates moving towards it from the south

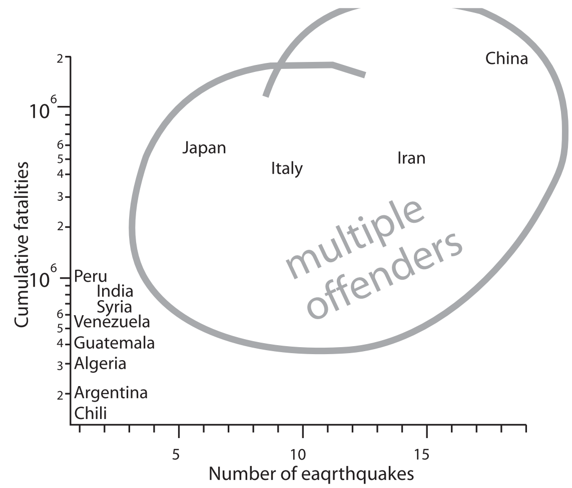

Figure 3: A plot of world's worst earthquakes (with more than 20,000 dead) shows a handful of nations where catastrophic earthquakes have occurred repeatedly. The plot was made before the Chengdu earthquake that killed 80,000 people. Should politicians in multiple offending countries should be educated about their earthquake hazards before taking office?

Why do we construct killer buildings?

There is a saying in earthquake engineering that earthquakes don't kill people, buildings do. But is it fair to blame the buildings? Surely it is the builders who are responsible, and if not them, the urban planners, or the collective wisdom of politicians and civic leaders, who fail to learn from past disasters? Whereas the earthquakes resulting in the Alpine/Himalaya collisional belt are due to natural causes, the death-toll is entirely man-made. The million people who have died from earthquakes in the past few decades have died due to the collapse of buildings, many constructed by the owners themselves. In the towns and cities the construction is undertaken by contractors and engineers. A short digression on why houses collapse is necessary in order to fully appreciate the simplicity of the problem we are addressing, even though its societal fix may be complex.

In an earthquake the ground accelerates sideways, and up-and-down. Usually the up-and down-motion is not a problem unless it approaches the acceleration needed to toss objects into the air. This is actually rather rare, but it has now been recorded near the epicenters of a dozen earthquakes. The main problem in an earthquake are the sideways accelerations that tend to topple tall buildings and to produce diagonal cracks in the walls of even one story buildings if they have heavy roofs. For example, an adobe building has a heavy roof with enormous inertia. It is propped up by thick mud walls which have strength only in the up-down direction. In an earthquake, a wall can easily be toppled sideways resulting in the roof being no longer supported. Concrete buildings have walls with greater strength but if the floor above is very heavy, they too will be stressed towards failure and eventually fail if the shaking continues for too long.

Although the reasons for building collapse are often attributed to faulty materials -adobe and mud, weak cement, brittle steel, heavy roofing materials, shortage of wood etc, the real culprit is often ignorance in assembly. Villagers unable to afford anything but indigenous materials will often have no recourse but to assemble their houses from mud bricks, or field stones. Experimental methods to tie the mud together with nylon string or even plastic bags are usually unknown to the villagers. The more wealthy villagers may construct concrete homes from concrete and stone, or poured concrete walls, but they seldom wish to lavish money on "invisible" parts of the building like solid foundations or strong concrete. Thus villagers will often mix 1 bag of cement with five or six bags of sand to make their expensive investment in cement go further. Sometimes they will mix the cement, not with sand, but with soil. They may also be tempted to skimp on steel inside the concrete forms, not realizing that the steel is there to prevent the concrete from tearing its apart during shaking. By far the most common problem with concrete structures assembled without engineering supervision is inattention to the way in which the steel rods inside the concrete are tied together, especially at joints between columns and walls. Construction requires adherence to very simple rules, but in the absence of guidance a villager, or a labourer, or even a licensed contractor, may not realize that his efforts at economy are meddling with the possible future death of the inhabitants of the home, or school or hospital. Earthquake engineers who visit damaged cities after an earthquake find no surprises. Damage in every earthquake, on every continent, looks the same: the same skimping of materials, the same incorrect assembly.

Earthquake relief efforts

After a catastrophic earthquake a relief effort is mounted to help the survivors. The procedure is familiar to every relief agency. Tent cities spring up to house the homeless. Bodies are buried. Temporary hospitals are erected. Blankets and food are freighted in or dropped from helicopters. Villagers start immediately to rebuild partially damaged homes, and backhoes and bulldozers clear the damaged streets of twisted steel and concrete. As soon as the debris has been removed a rebuilding program is implemented usually in the form of government subsidized dwelling units.

Of relevance to the long term earthquake hazard problem is the awareness retention time - how long does a society remember the catastrophe? The funds to fix the catastrophe are abundant in the first few months following an earthquake, but interest fades rapidly. The "half-life" of public and even national interest is about two months, even for a severe earthquake. The half-life of interest for the Sumatra-Andaman tsunami earthquake was an exception because it was multinational disaster with an immense reach. The memory of an earthquake survives for as long as the news media can sell it.

In contrast, the diminution of interest in a disaster takes longer to fade for people affected directly by it. In Iran it has been noted that it make take 1 or IV2 generations before the lessons of the earthquake are completely forgotten. Villagers desist from reconstructing an adobe village that may have been completely destroyed in an earthquake for perhaps 30 years, but in the absence of government intervention, adobe construction is first used to house animals, and eventually takes over as the dwelling of choice for the villager.

Reconstruction

Cities destroyed by earthquakes are never abandoned nor do rural communities leave their fields and orchards. Hence in-situ reconstruction commences in the immediate aftermath of an earthquake. Government authorized reconstruction in an epicentral region is undertaken with caution, especially if aftershocks continue to serve as a constant reminder about the intrinsic need for earthquake resistance. It is usual for the government to seek advice from engineers about what codes should be enforced in the construction of new buildings. When prompted, engineers either adopt the safest possible course - they envisage the highest possible intensity of shaking - or they seek advice from the seismological community. In turn the seismologists look to history -either in the form of written historical accounts for the past several centuries, or in the form of seismic records available since 1900 or so, but typically available only since 1960 when a reliable global network of seismometers was installed. From the historical record statistics are developed that can provide estimates of the strongest possible shaking anticipated in the next 30 years, a typical life-span for a modern building in a city.

Seismic hazards - possible future shaking

Statistics about the probability of future seismicity exists in many parts of the world, even in those that have not experienced a recent earthquake. The information is often summarized in the form of a colored seismic hazard map: pastel colors indicate regions where earthquake shaking is unlikely, vivid reds and orange indicate regions where earthquake shaking is very probable. The maps are used to provide regional engineering guidelines for critical facilities - power stations, large bridges, dams, hospitals, fire stations and schools. Each country has a map of seismic hazards based on its historical and numerical data on earthquakes. Sometimes a country may have several seismic Where earthquakes are frequent, and the historical record exceeds 1000 years long, such as in Japan, seismic hazard maps can be used as a reliable guide to future expectations.

In a following section I address problems specific to estimating seismic hazard in Baluchistan, Pakistan, India, Bangladesh, Nepal and Bhutan. Here I address the general questions of "unexpected" earthquakes, which raise issues about the utility of regional hazard analysis. An earthquake might be classed as unexpected because its magnitude exceeds all previous expectations for the region. This situation arises in a region of known seismic hazard where a constant background of moderate, or large earthquakes occur, but where the worst case scenario earthquake is not considered likely. An example would be the 2004 Mw=9.1 Sumatra/Andaman earthquake with its 1600 km long rupture zone. The length of this rupture exceeded by an order of magnitude all previous earthquakes in the region, some of which had indeed produced tsunamis. Alternatively an earthquake may be unexpected because no earthquakes are known at all in a region. An example, of this might be the Mw>7.5 New Madrid earthquakes of 1811/12 in the central USA. The early settlers had no knowledge of earthquakes there because no historical record existed in the region. Parts of Australia to this day have earthquakes in unexpected places. The Latur earthquake of 1993 could be considered an earthquake in this category, although weak earthquakes are documented historically throughout southern India.

More commonly an earthquake is classed as unexpected because the link between what is known (by seismologists), and what needs to be done (by civic authorities), has yet to be forged. The Kashmir November 2005 earthquake, for example, was considered unexpected by the planning authorities in the region, but was very much expected by seismologists. In a publication celebrating the centennial of the Kangra April 1905 earthquake, just five months before the Kashmir earthquake, the region had been identified as sufficiently mature to host a Mw=8 earthquake. This statement was made in the aftermath of the Indonesia earthquake, with the knowledge that conservative estimates of future hazard by seismologists did not serve well the interests of the society.

Prediction vs. forecasting

In suggestion that civic authorities in Pakistan and India had been dealt an unexpected earthquake because seismologists did not make a strong enough case for the inevitability of the Kashmir earthquake, one could indeed argue that all that all that was missing in the forecast was the timing of the event. The location was within a hundred km, and thus more or less correct, and the magnitude within a factor of two. Thus, had the announcement been in the form of a prediction, where the place and magnitude *and time* had been specified by a trusted authority, is there any doubt that something would have been done to mitigate the disaster?

Well, yes, had there been a trusted authority available, and had the prediction been accurate, one could indeed have saved 80,000 lives by bringing everyone into the fields, away from the landslides and falling buildings in the hour before the earthquake. *But the disaster relief effort would still have been needed to feed, and house the survivors.* In five months it would not have been possible to reinforce the 15,000 schools that collapsed (100 retrofits per day!), or the hundreds of thousands of homes that had to be rebuilt. Thus an accurate prediction of an earthquake does not make the disaster relief effort go away.

However, earthquakes cannot be predicted yet, even where we have dense seismic networks as in Japan and California. So why should we entertain hopes for improving our knowledge of future earthquakes in the SAARC countries where seismic networks are sparse and seismic data historically incomplete? The answer to this question is that it is ill-posed. A moment's reflection reveals that we really do not want to *predict* earthquakes. Instead we need to *forecast* them. This sounds like a pedantic distinction until we recognize the implications of prediction. *A prediction* conjectures that an earthquake is about to happen, whose consequences are undesirable or potentially catastrophic. It more than suggests that damage that will be sustained by a specific city at a specific time in the future, usually meaning in an hour, or a week or a month. In contrast, an earthquake *forecast* tells us of probable earthquakes in a general region. It can alert us to build cities in certain areas that can resist expected shaking. Few effects of earthquakes cannot be mitigated against. In principle no building need fall in an earthquake, no person need be injured, and no emergency response plan need be in place. Forewarned is forearmed.

Knowing that an earthquake is about to happen will not prevent that city from collapsing if it has been constructed incorrectly, yet knowing that an earthquake of a certain severity will probably occur during the life time of structures currently on the drawing board, or under construction, is of immense utility. Correctly designed buildings will not kill their occupants, more importantly they will not require reconstruction after the earthquake. Earthquake forecasts, if followed through by societies at risk, offer an absence of future disaster, or at least a greatly mitigated impact of future earthquakes. One has only to compare the effects of M=7.6 earthquakes in California (Loma Prieta 1989 with 62 fatalities, Landers 1992 with 3 fatalities) with M=7.6 earthquakes in Pakistan (Quetta 1935 with 35,000 fatalities; Kashmir 2005 with 80,000 fatalities) to realize that this is no idle statement. In California, earthquake resistant construction is mandatory; in Pakistan earthquake resistant codes exist but they are not diligently applied to dwellings, or as recent events have shown, even to civic structures such as schools and hospitals. It is unfortunate that most, if not all cities on the Indian plate and its boundaries are unprepared for an earthquake. It is surely impossible to believe that this situation will remain unchanged indefinitely, but past experience shows that it requires an earthquake to catalyze earthquake resistance. Thus, it is almost an axiom that a damaged city be reconstructed to resist further shaking. It is rarely the case that the example of local destruction is extended to the general problem of regional construction.

Earthquake hazards on the Indian plate - the earthquake cycle

A distinction can be made between the giant plate boundary earthquakes that occur at the edges of the India plate as is grinds past its neighbours (Myanmar to Indonesia, or Makran to Afghanistan) or where it ploughs beneath southern Tibet (Himalaya), and the moderate but still damaging earthquakes that occur deep within the ancient continent of India. The distinction is important, and is linked to the way in which these earthquakes are driven. Central to our understanding of earthquakes at a plate boundary is the concept of the earthquake cycle. Earthquakes occur when the stress and resulting strain in rocks approach and exceed their breaking point. At the moment of rupture the strain in the surrounding rocks is drained almost to zero, but the continuing motion of the Indian plate starts immediately to re-generate the strains responsible for the next earthquake.

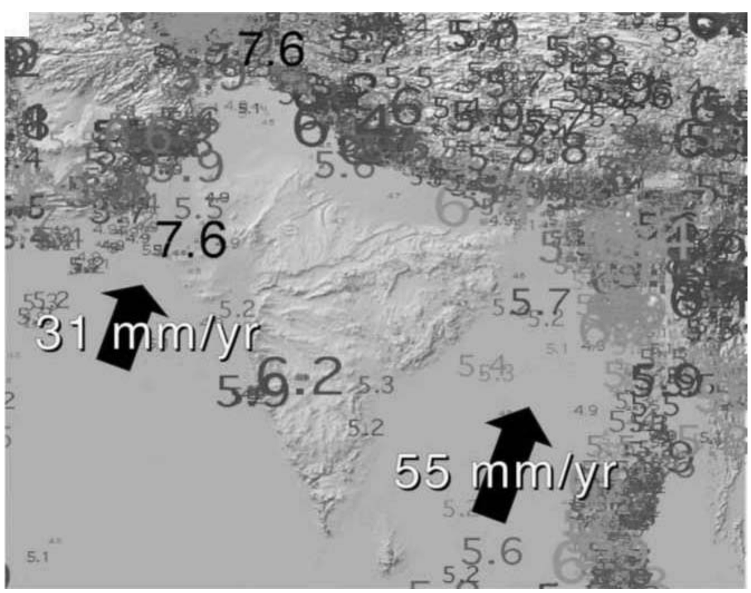

Figure 4: Earthquakes in the past 45 years color coded according to depth (green is deeper than 40 km, red is shallower than 10 km), and the GPS measured velocity of motion of India towards Asia. The velocity is higher in the east because the Indian plate is rotating slowly counterclockwise relative to Asia as it collides. The mean velocity of India towards Asia is *1 mm per week!*

When the breaking point is again approached a second earthquake will occur. The relentless and repeatable nature of this process is described as the earthquake cycle, and the time between earthquakes is known as the recurrence interval, or the renewal time. On the San Andreas fault, for example, earthquakes have occurred dozens of times in the past 2000 years and it is possible statistically to estimate the recurrence interval between earthquakes. In the Himalaya we know a cycle must exist but we have no clear example of a single repeating earthquake. In the Indian plate we are not even certain of the applicability of the earthquake cycle as described above.

Earthquakes in the Himalaya

Remarkable strides in our understanding of Himalayan earthquakes have occurred in the past two decades. First of all we know that less than half of the velocity of collision between India and Asia is manifest in the Himalaya. Thus roughly 18 mm/yr of its average 45 mm/year convergence drives the earthquakes of the Himalaya. This information comes from GPS measurements along the length of the Himalaya. Secondly we have researched everything that is known about the past 200 years of damaging earthquakes and have more precisely determined their locations and magnitudes. Thirdly, the work of a group of Indian, French and US scientists has led to a more complete view of the last 1000 years of earthquakes in the Himalaya. This shows that the recent earthquakes to be much smaller than those that occurred in Medieval times. I summarize this information in Figure 5. The red and white lines indicate the region between which Himalayan ruptures occur - between earthquakes the lines converge by 18 mm each year. Earthquakes that have occurred in the past 200 years are indicated by a pink rupture zone and a magnitude. The white arrows indicate where evidence for much larger earthquakes has been exhumed. These megaquakes occurred in the 12th, 15th and 16th centuries, and have been discovered as offsets of recent sediments in trench excavations conducted by geologists Thakur, Wesnousky, Kumar, Yule and Lave. What is remarkable is that the size of these earthquakes (M>8.6) resulted in 20 m of slip in each earthquake, and allowing more than half the length of the Himalaya to advance over India! To place this in perspective, the more recent earthquakes slipped by only 5-7 m and allowed only 15% of the contact zone to slip. Only one of these dozen earthquakes produced a surface rupture -Kashmir, 2005.

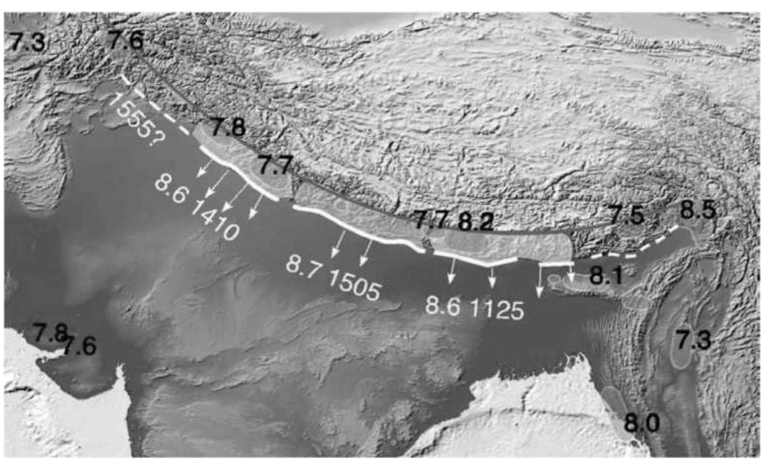

Figure 5. Plate boundary earthquakes in the past 200 years (pink with Richter magnitudes) are much smaller than occurred in Medieval India (yellow). The arrows indicate where earthquake slip of 8-24 m has been measured in trenches. From the amount of slip the magnitude of these earthquakes has been estimated. Carbon 14 provides the dates of the earthquakes. Earthquakes must eventually fill the entire plate boundary, including Kashmir and Assam. It is possible that a repeat of the 1125 megaearthquake (M=8.4 to M=8.6) could occur, but smaller earthquakes (M=8) are more probable.

The megaquakes with 20 m or more of slip earthquakes cannot occur more frequently than once every 1000-1200 years, given the observed GPS velocities across the Himalaya. The smaller M=7.6 (Kashmir) to M8.2 (Bihar/Nepal) earthquakes, however, can occur about once every 500 years, and in dozens of locations along the Himalaya. Calculations show that if you take all the slip from all the earthquakes we known of in the past 1000 years, it is balanced by all the slip that GPS measurements tells us has been delivered in the past thousand years. This means that we have observed one complete earthquake cycle in the Himalaya. In practice we know we have not quite seen a complete earthquake cycle. There are patches still to go - in the Pir Pinjal south of central Kashmir for example, and in Assam and Sikkim. These patches (the blank areas and dashed lines of Figure 5) have dimensions sufficient to generate M=8 or M=8.2 earthquakes. These should possibly be the areas of greatest concern for earthquake preparations.

Flexural earthquakes in the mid continent

The Indian subcontinent forms part of the Indian plate, a more than a million square km region of continent and sea floor that behaves much like a huge concrete block, with no cracks and therefore no obvious changes in shape. Indeed a glance at the earthquake map (Figure 4) suggests that no earthquakes occur there. Yet earthquakes do indeed occur and their resulting death toll is quite alarming.

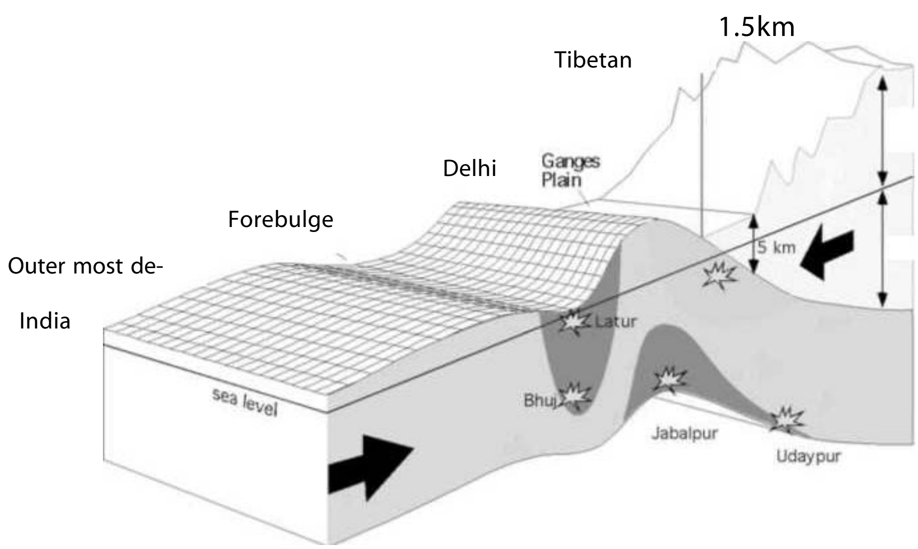

Figure 6. Schematic view of the Indian plate being pushed northwards beneath the Tibetan plateau. The northern depressed leading edge forms a bulge in central India and a slight depression in southern India that cause the plate to rupture and generate earthquakes, i.e. the forces of collision are felt 1500 km deep into the Indian plate, far from the Himalaya that marks the of great earthquakes where the Asian and Indian plates collide. Cities of India stream through this stress field slowly and earthquakes can occur almost anywhere. The northern edge of the Indian plate is flexed downwards more than 20 km by the weight of the Himalaya and by the compressive forces of India's collision with Asia. The 6-km-deep flexural depression near the Himalayn foothills has filled with sediments from the Ganges, raising a 450 m high bulge in central India. These same flexural forces form a 40 m depression between Bombay and Hyderabad. This flexed surface is responsible for the general stress regime that drives earthquakes in India. Shallow reverse faulting occurs near this depression (e.g. the Latur earthquake), deep reverse faulting occurs beneath the central Indian Bulge and the Ganges plain (e.g. the Jabalpur earthquake).

Earthquakes occur within it so scientists have looked diligently for the telltale strain changes that should drive these earthquakes, yet attempts to measure horizontal strains in the plate using GPS methods show its dimensions to be stable at the resolution we can measure it (about 1 mm per 1000 km). However it does have the property that it can be flexed in a vertical sense, just as the strongest bridge will deflect a cm or so in the presence of a tank passing across it. The Indian plate is about 40 km thick, but is flexed downward 20 km where it is being pushed beneath the Tibetan plateau by the immense horizontal forces of the collision. Its leading edge has sunk to about a depth of 5 km beneath the Himalayan foothills. The flexure causes the plate in central India to rise about 500 m above the Ganga plains and then to sink again near a line passing south of Bombay and north of Madras before it rises again to a neutral position.

The rocks near the crest of the bulge in central India are in tension and the rocks at the base of the bulge are in compression. Calculations show that these forces are thousands of bars, more than sufficient to generate earthquakes. The Jabalpur earthquake of 1997 (38 fatalities) was caused by compression at the base of the plate. South of the bulge, where the plate is depressed slightly by the forces of collision, the disposition of the stresses is reversed, with tension at the base of the plate and compression at the surface. It is here at the surface that the Latur earthquake of 1993 occurred (9728 fatalities). The earthquake stresses, being highest near the surface ruptured the surface rocks.

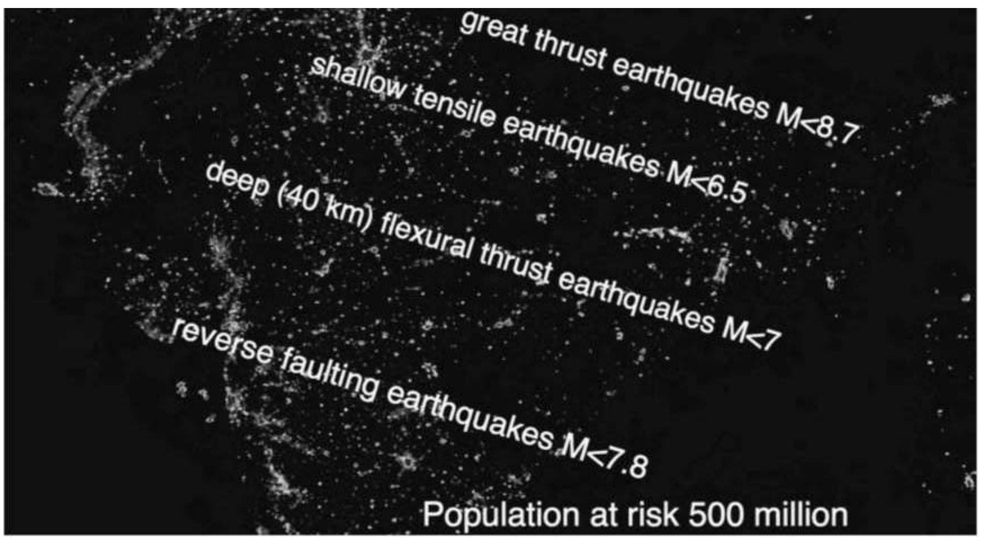

Figure 7 : Earthquakes in mid-continent superimposed on the night luminosity of Indian cities. Delhi is the bright light above the 11 in shallow, Karachi is visible to the west, Mumbai below the r of 'reverse' and Calcutta and Chittagong in the East. Offshore oil rigs and flames illuminate the sea west of Mumbai and the land in NE Assam.

The flexural forces of the India's collision with Asia thus produce damaging earthquakes more than 1000 km south of the Himalaya. But the earthquakes here do not occur very frequently. In fact it is rather difficult to engage in an intelligent estimate of where the next flexural earthquake will occur based on historical statistics because there far too few earthquakes to form statistical estimates. Even the notion of an earthquake cycle may in fact be inappropriate in central India. The reason for this is because the stress field generated by the forces of collision is fixed in space, but the Indian plate passes through this stress field at a rate of 2 cm each year. Over many millions of years a surface rock will first experience compression, then tension, then compression again as it passes from southern India to beneath Tibet. The cyclicity of earthquakes is substantially modified by this long physical term process. Unlike at the plate boundary where continued slip is driven by unstoppable steady plate displacement, the slip on individual faults in midcontinent is cumulatively not large, and the notion of an earthquakes cycle is inappropriate.

Earthquake hazard maps - a fatal flaw.

From the foregoing it is clear that the physical reasons for the occurrence of earthquakes on and near the Indian plate are more or less understood, and that their continued recurrence is inevitable. To move this information from scientific curiosity to social engineering, however, one needs a hazard map - a map showing the probability of future shaking at certain acceleration levels. Yet earthquake hazard maps are made, not from physical models of earthquakes, but from a history of past earthquakes. This immediately encounters a fatal flaw in the Indian plate. To be successful the maker of a seismic hazard map must assume that the available history of earthquakes includes several earthquake cycles!

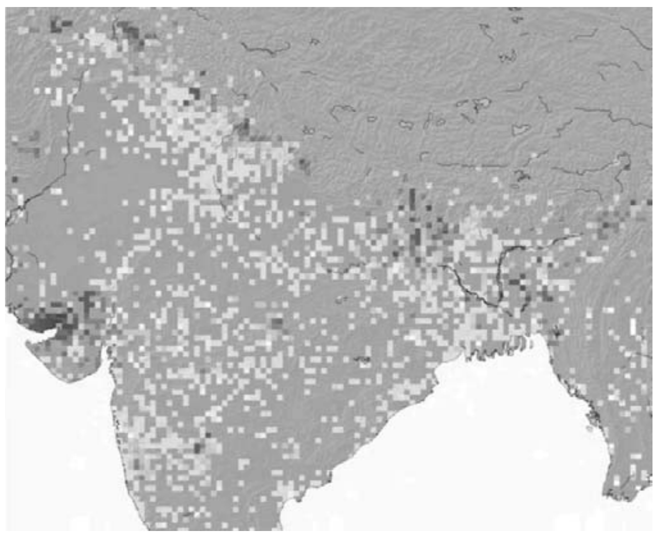

Figure 8. A seismic hazard map in progress. The above map indicates the highest shaking intensity reported in the past 400 years in the binned areas from historical records in India (from a study by Martin and Szeliga submitted in 2008 to the Bulletin of the Seismological Society of America). If one had 100,000 years of data the red squares would form bands parallel to the Himalaya and along the plate margins in Afghanistan and Burma. Light damage starts with yellow colors, orange colors indicate moderate damage, substantial damage is indicated by red colors. White, blue and green are places where (at present), no damage has been sustained by earthquakes.

In the above discussion of Himalayan and continental Indian earthquakes I have pointed out that we may have *almost* one complete earthquake cycle in the Himalaya, but we have only *a small fraction* of an earthquake cycle in continental India. This means that all hazard maps generated to date are almost certainly wrong. They indicate where earthquakes have been, they do not tell us where earthquakes will not occur in the future.

Two examples are instructive. If one looks at an earthquake hazard map of India for 1980 you would have no inkling of a pending earthquake about to occur in Killari/Latur. The hazard map of 2000 now paints a bright red color around the region of this earthquake - a bull's-eye proclaiming the hazardous nature of this region. Similarly the Pakistan 1980 hazard map shows no special danger from earthquakes in Kashmir. Yet a recent seismic hazard map admits the region is seismically treacherous by now changing the color from orange to red.

This is equivalent, in the game of golf, to making a hole for the ball after it has been launched. This does not mean that earthquake hazard maps are useless for engineering. With the right amount of data, such maps are an important guide to future seismicity. So how much of the right kind of data would we need to develop a reliable hazard map? The answer is rather distressing - a statistician would need about 10,000 years of history in the Himalaya and 100,000 years of history in the central Indian plate to do the job properly. Clearly we cannot wait that long.

Joining the dots - common sense and education

We have seen that, if the history is short compared to the recurrence interval for earthquakes, hazard maps based on history may give us a misleading view of the future. Seismologists are developing methods to needs to improve the odds of forecasting the future by blending some physics into the mix. A litany of probabilistic approaches would fill many pages, but they would remain possibilities and probabilities - intelligent manipulation of grossly inadequate input data. The expression "garbage in-garbage out" can be applied to such manipulation.

One way to estimate hazards is to simply join the red dots on Figure 8. Thus the red dots are near former earthquakes, so the most likely areas for future earthquakes lie between the red dots. Although this may seem haphazard it immediately identifies three areas considered overdue for Himalayan earthquakes: The Pir Pinjal Kashmir, western Nepal and Assam. Rather surprisingly it would also result in much of the peninsula lighting up as a result of possible future flexural seismicity. The method gives us a pessimistic view of seismic hazard with no estimate of time.

The safest way around the dilemma of earthquake hazards is to accept that many parts of the Indian plate will indeed have earthquakes, and to mandate levels of earthquake resistance on all new construction in these areas. Were earthquake resistant guidelines adhered to today on all new construction in all earthquake prone regions, in less than three decades many cities would be largely invulnerable to earthquake losses. This is because structures in cities have a certain lifetime. A rule of thumb is that structures usually live for thirty years before they are replaced with a new one. In practice some structures survive for hundreds of year, but a glance around most cities will show these to be in the minority.

How much would such a program cost? Engineers note that an additional 10% spent a construction will often render a dwelling earthquake resistant. Simple remedies exist to hold a building together during earthquake shaking. Earthquake resistant guidelines exist in most SAARC countries, so the know-how is already there. What is needed is the willpower to mandate earthquake resistant construction, and this can only come about through education - education of our leaders, town planners, contractors, labourers and ultimately the owners of dwellings.

A case study from Baluchistan

In 1935 an earthquake killed 35000 people in Quetta. In the aftermath of the earthquake the authorities mandated earthquake resistant construction throughout the region. As a result Quetta was reconstructed to resist earthquakes. No large earthquake has since occurred in Quetta.

Two months ago a pair of M6.4 earthquakes, the second slightly larger than the first, occurred about

50km NE of Quetta. In the surrounding regions the buildings that fared the best were those that were built shortly after the 1935 earthquake and incorporated earthquake resistance. Nearly all the schools collapsed at the epicenter because they did not include earthquake resistance.

Whose fault was this? Was it the local contractors, the government, or the politicians we must blame? I believe the fault is that the lessons of the 1935 earthquakes had been forgotten. In a very real way it is the seismologist who is at fault for not continually reminding people that earthquakes will recur throughout the plate boundary and interior of the Indian plate. It is now a generation and a half after the 1935 tragedy, but only 50 km distant. The lesson is that we must not forget our seismic history. City planners must be educated on the earthquake potential of the regions in which they work - it is part of the language they must speak to qualify for their vital role in keeping their countrymen safe.

Conclusions

The collision of the Indian plate with Asia results in earthquakes that will not go away. Since the next earthquake is invariably not in the location of the last earthquake, it is vital that the momentum to rebuild weak structures, especially schools and hospitals, should extend to regions far from the one that has just been destroyed. Kashmir is being rebuilt following damage in 2005, but what about the Pir Pinjal Himalaya and Assam and Sikkim where future earthquakes are anticipated? No reconstruction is occurring there because a disaster has yet to strike. But this is simply inviting disaster. The cost of reconstruction is appallingly high, but the cost of incorporating earthquake resistance into new construction is only an additional 10%. A simple plan would be to mandate earthquake resistance into all new construction since through the process of urban renewal most cities will in 30 years be more than twice as resilient as they are now. Simple plans lack drama, but what civic leader would be willing to be blamed for the deaths of thousands of people for ignoring such an important concept?

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