Recent Actions Taken in India Towards Seismic Risk Assessment and Reduction

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SUMMARY
This paper describes briefly the measures recently taken and being implemented in India towards seismic risk assessment and risk reduction. A seismicity data base has been prepared for the Indian subcontinent. Homogenized earthquake catalogs are prepared using scaling relations. Probabilistic seismic hazard maps for the Indian subcontinent have been prepared. Guidelines for seismic microzonation have been prepared and microzonation of major cities has been taken up. About 450 strong motion records from 167 earthquakes have been obtained and ground motion prediction equations for different tectonic environments have been formulated. Indian Ocean Tsunami Warning System has been established by MoES, Government of India. A Vulnerability Atlas of India has been prepared by BMTPC for formulating natural disaster prevention, preparedness and mitigation plans for different regions of India. Seismic base isolation and structural health monitoring techniques are also discussed. A national program for capacity building of engineers in earthquake risk management has also been launched .

Keywords: Homogenized catalog, Seismic hazard map, Microzonation, Tsunami warning system, Vulnerability Atlas

1. INTRODUCTION

Indian subcontinent is one of the most earthquake prone regions of the world. Over 54 % of India's region is vulnerable to earthquakes with about 12% of the land being liable to severe earthquake shaking with MSK Intensity IX or more and 18% area being susceptible to Intensity VIII. Some of the great Indian earthquakes include the Rann of Kutchch earthquake of June 16 , 1819 (M 8.3), the Shillong earthquake of June 12, 1897 (M_w 8.7), the Kangra earthquake of April 4, 1905 (M 8.0), the Bihar-Nepal border earthquake of January 15, 1934 (M 8.3) and the Assam earthquake of August 15, 1950 (M_w 8.1) which had caused widespread destruction and loss of life.

Among the recent earthquake activity there are several moderate-to large magnitude earthquakes, e.g., the September 30, 1993 Killari earthquake (M_w 6.8) in the southern block of the shield, the May 22, 1997 Jabalpur earthquake (M_w 6.0) in the central SONATA zone, the October 20, 1991 Uttarkashi (M_w 6.8) and the March 29, 1999 Chamoli (M_w 6.8) earthquakes in the western Himalaya tectonic zone, the January 26, 2001 Bhuj earthquake (M_w 7.7) in the Kutchch rift basin in the western part of the shield and the Sikkim earthquake of September 18, 2011 (M_w 6.9) in the Northeast region. In addition to these, the great Sumatra earthquake of 26 December, 2004 (M_w 9.3) generating a destructive tsunami caused unprecedented loss of life and destruction in the Indian ocean coastal areas, and October 8, 2005 Pakistan (Muzaffarabad) earthquake (M_w 7.6) also caused significant destruction in the North-west Indian region.

Earliest compilation of catalog of Indian earthquakes from earliest times to 1869 was by Oldham in 1883. Recently, there has been several studies to prepare homogeneous earthquake catalogs for Indian region (Yadav et al., 2009; NDMA, 2011; Das et al., 2012a; Nath and Thingbaijam, 2012). Probabilistic seismic hazard maps for the Indian subcontinent have been prepared (NDMA, 2011; Nath and Thingbaijam, 2012) and other researchers. Several other seismic studies have also been carried out for seismic risk assessment of different seismogenic zones.

Microzonation involves incorporation of geological, seismological and geotechnical aspects for land use planning for earthquake effects so that engineering structures can be designed which are less susceptible to earthquake damage. Seismic microzonation of major cities has been taken up for better land use planning and earthquake risk reduction. A Seismic Microzonation Handbook and Guidelines for Seismic Microzonation have been prepared by the Ministry of Earth Sciences (MoES), Govt. of India, New Delhi (MoES, 2011).

Strong motion instrumentation around active faults/thrusts and in areas of high seismicity has been strengthened providing near-field strong motion data. In the last 8 years, strong motion data from 167 earthquakes including the recent September 18, 2011 Sikkim earthquake (M_w 6.9) has been recorded. Based on recorded strong motion data, ground motion prediction equations for different tectonic environments have been formulated by different researchers (e.g., Sharma et al., 2009; Mandal et al., 2009; Nath et al., 2009; Gupta, 2010).

The Indian coastal areas are vulnerable to the tsunamis generated by earthquakes from the two potential source regions, the Andaman-Nicobar-Sumatra Island Arc and the Makran Subduction Zone. The Indian ocean tsunami of December 26, 2004, generated by the great M_w 9.3 Sumatra, Indonesia, earthquake brought heavy destruction and loss of life in Indian coastal areas. With the aim for disaster reduction from future tsunamis that are likely in the Indian ocean, Govt. of India has established an Indian Ocean Tsunami Warning System (IOTWS) which has been operational since September 2007. The functionality and reliability of IOTWS has been tested during some earthquakes occurring in this region including the recent 8.6-magnitude earthquake of April 11, 2012 centered at a depth of about 33 km beneath the ocean around 495 km from the provincial capital of Banda Aceh, off Sumatra, Indonesia.

For identification of vulnerable areas with reference to natural hazards causing damage to the housing stock and related infrastructure, a 'Vulnerability Atlas of India' was prepared in 1997 by Building Materials and Technology Promotion Council (BMTPC), Ministry of Housing and Urban Poverty Alleviation, Govt. of India. A revised version of this Atlas has been published in 2006 (BMTPC, 2006). This Atlas is immensely useful for formulating the natural disaster prevention, preparedness and mitigation plans at a broader level in different regions of India.

The base isolation technique has been applied to few selected buildings in seismic zones IV & V on experimental basis including the construction of three buildings in Delhi. A laminated lead rubber bearing has been developed for a complex building (Govardhan et al., 2011) and stochastic response of building frames isolated by lead-rubber bearings has been studied (Jangid, 2010).

A national program for capacity building of engineers in earthquake risk management has been launched for creating awareness of earthquake engineering practices in the country, disaster prevention and human resource development by the Ministry of Home Affairs, National Disaster Management Division, Govt. of India. The efforts include the programs for disaster prevention before the earthquake, disaster management during the earthquake and post earthquake rehabilitation programs.

This paper describes briefly the measures recently taken and being implemented in India towards seismic risk assessment and risk reduction.

2. EARTHQUAKE CATALOG FOR THE INDIAN REGION

A catalog containing earthquake events of M > 5.0 for the Indian region (0^0-40^0N, 60^0-100^0E) spanning the period 1505 to March, 2010 has been prepared by India Meteorological Department (IMD), New Delhi. A plot of seismicity (M > 5.0) for the Indian region is shown in Fig.1 (IMD, 2010). Homogenized earthquake catalogs have been prepared for India and adjoining region (2^0-40^0N, 61^0-100^0E) by NDMA (2011) consisting of 38,860 events with $M_w \geq 4.0$, and also by Nath and Thingbaijam (2012) covering the period 819 to 2008 for events of $M_w \geq 5.0$. Homogenized catalogs have also been prepared for different tectonic sub-regions (e.g., Yadav et al., 2009; Das et al., 2012a).

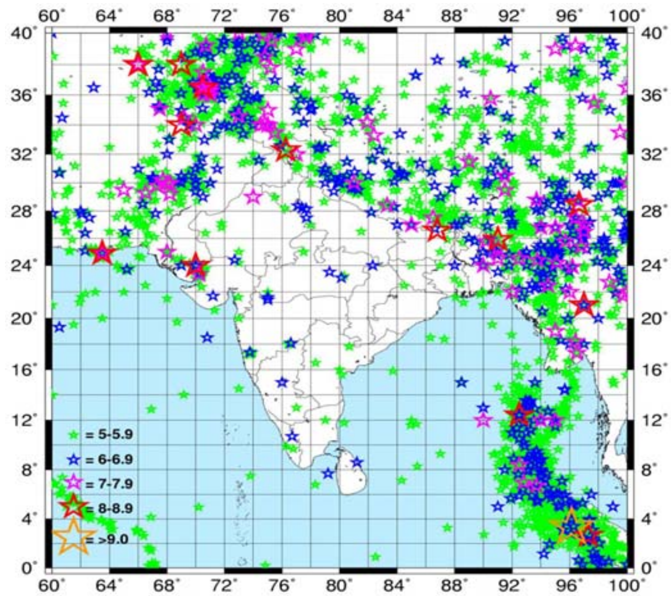

Figure 1. Seismicity of India showing earthquakes with M > 5.0 by IMD(2010)

3. SCALING RELATIONS

3.1. Magnitude Conversion Relations for Northeast India and Adjoining Region

Magnitude conversion relations between m_b, M_S and $M_{w,GCMT}$ have been developed for different magnitude ranges for Northeast India and adjoining region by Das et al.(2012a) using the data for the period 1964 to 2006 from ISC (http://www.isc.ac.uk/search/Bulletin), NEIC(http://www. neic.usgs. gov/neis/epic/epic-global.html) from GCMT (http://www.globalcmt.org/CMTsearch.html) databases. Other studies have also reported scaling relations between different magnitude types (Thingbaijam et al., 2008; Yadav et al., 2009; Das et al., 2011). These relations differ in their type as being SR, ISR, or OSR, data sets used and range of magnitudes covered.

3.2. Magnitude of Completeness for Different Catalogs

Magnitude of completeness have been determined for the declustered homogenized catalog for Northeast India region pertaining to four different time periods namely, 1897-1963,1964-1990, 1964-2000 and 1964-2010. The M_c values obtained are 6.0 ± 0.23, 4.6 ± 0.12, 4.3 ± 0.22, 3.7 ± 0.22, respectively, for the four catalog periods (Das et al., 2012b). M_c values for other catalog periods and seismic zones and regression parameters for GR relations have also been reported by other researchers.

4. GROUND MOTION PREDICTION EQUATIONS

In a scenario-based deterministic hazard assessment, numerical modeling and computational schemes are often employed for realistic ground motion simulation. However, ground motion prediction equations (GMPE) are generally used in probabilistic seismic hazard analysis. Several GMPEs have been developed for the Indian region and some of the recent studies in this regard are as given below.

a) For Himalayas and Zagros region, M 5.0-7.0, $R_{jb} \leq 100$ km (Sharma et al., 2009).
b) For Gujarat region, M_w 3.2-7.2, $R_{jb} \leq 300$ km (Mandal et al., 2009).
c) For North east India, M_w 4.8-8.1, $R_{rup} \leq 100$ km (Nath et al., 2009).
d) For Indo Myanmar Arc zone, M_w 6.3-7.2, $R_{rup} \leq 375$ km (Gupta, 2010).
e) For Gujrat region, M 3.0-5.7, $R \leq 120$ km (Mohan and Joshi, 2012).

5. PROBABILISTIC SEISMIC HAZARD MAP OF INDIA

Several studies have been devoted to determine and parameterize the seismogenic source zones underlying the Indian subcontinent. A seismotectonic atlas of India and its environs has been published by GSI in 2000 (Dasgupta et al., 2000). A probabilistic seismic hazard map for the Indian subcontinent has been prepared by National Disaster Management Authority, New Delhi (NDMA, 2011) based on a homogenized catalog containing 38860 events of magnitude $M_w \geq 4.0$ spanning the period 2474 BC to 2008 AD. A seismic hazard map of India with return period of 475 years, i.e., 10% probability of exceedance in 50 years is given in Fig 2. Several other studies have also been devoted for estimating PGA values for Indian subcontinent and its sub-regions (e.g., Bhatia et al., 1999; BIS, 2002; Sharma and Malik, 2006; Jaiswal and Sinha, 2007; Anbazhagan et al., 2009; Mahajan et al., 2010; Menon et al., 2010). In a recent study, Nath and Thingbaijam (2012) has also prepared a probabilistic seismic hazard map of India. However, the PGA values reported by Nath and Thingbaijam (2012) are found to be much higher as compared to the values reported in other studies including BIS (2002). The differences in the estimated hazard distribution can be attributed to several factors such as the attenuation relations employed, seismotectonic provinces, seismicity parameters and seismogenic sources framework amongst others.

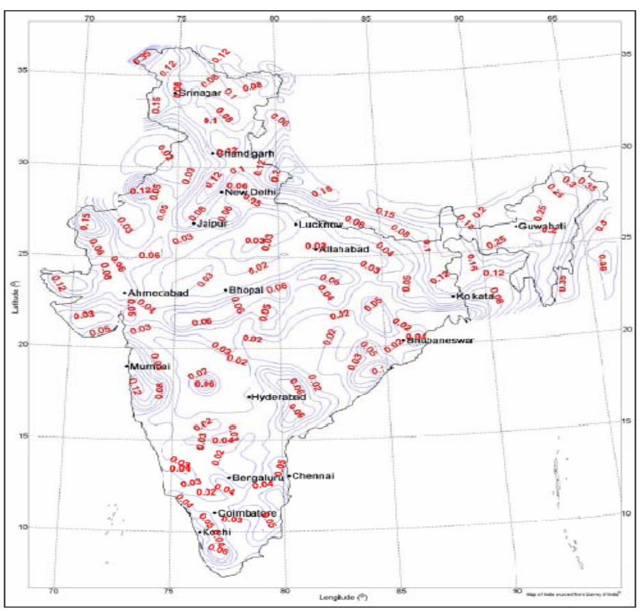

Figure 2. Peak ground acceleration contours with 10% probability of exceedance in 50 years (return period, 475 years) for hard rock sites (NDMA, 2011)

6. SEISMIC MICROZONATION OF MAJOR URBAN CENTERS

Urban seismic risk is rapidly increasing in India on account of high population growth and the pressure on urban development into areas susceptible to earthquakes. In order to provide uniform guidelines and systematic approach for microzoning the seismically vulnerable urban centers of the country, a Seismic Microzonation Handbook and a Seismic Microzonation Manual were released on October 14, 2011 by the Ministry of Earth Sciences (MoES), Govt. of India. This seismic microzonation handbook embodies detailed explanation of all the geological, geophysical and geotechnical methodologies available for systematic seismic microzonation studies (MoES, 2011). First level seismic microzonation has already been completed for several cities including Jabalpur, Sikkim, Guwahati, Delhi, Bangalore, Ahmedabad, Dehradun, Chennai and Chandigarh.

The problem of earthquake risk is even more severe for cities like Gangtok and Guwahati, in the Northeast India, which lie in Zone V of Seismic Zonation Map of India (BIS, 2002). Seismic hazard and microzonation atlas of the Sikkim Himalaya has been prepared (DST, 2006). A preliminary seismic microzonation and population risk map for the Guwahati urban area is given in Fig. 3 (DST, 2007).

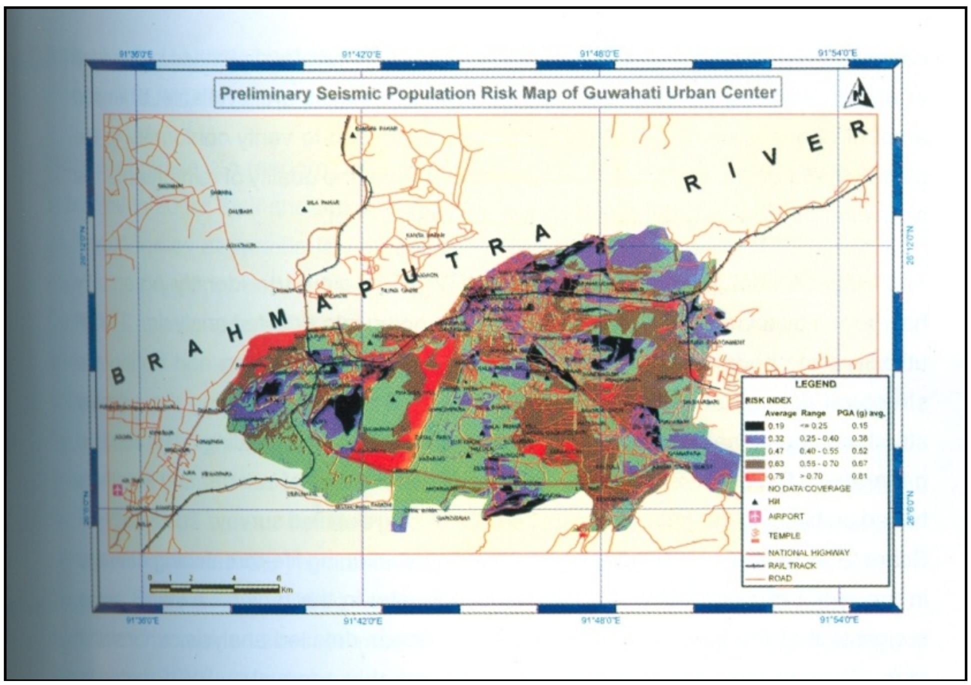

Figure 3. Preliminary seismic population risk map of Guwahati urban area (DST, 2007)

7. STRONG MOTION OBSERVATIONS

Under the Mission Mode Program on Seismology of the Department of Science and Technology (DST), Govt. of India, about 300 state-of-the-art digital strong motion accelerographs were installed in north and northeast India in 2004 onwards to monitor earthquake activity in seismic zones V & IV, and in some heavily populated cities falling in seismic zone III of the Seismic Zonation Map of India (BIS, 2002), in the states of Himachal Pradesh, Punjab, Haryana, Rajasthan, Uttarakhand, Uttar Pradesh, Bihar, Sikkim, West Bengal, Andaman and Nicobar, Meghalaya, Arunachal Pradesh, Mizoram and Assam. This network was further strengthened in 2007 by adding 20 digital strong motion accelerographs in the Delhi region.

This state-of-the-art instrumentation has partially filled the long-felt need for monitoring ground motion generated by earthquakes in the Himalayas using modern strong motion instruments. Since its installation about 450 strong ground motion records from 167 earthquakes have been obtained. The data recorded by this network is disseminated through the website http://www.pesmos.in. About 100 research workers have registered at this web site and are now using these records for their research work.

Recently two earthquakes occurred in different parts of India, i.e., Sikkim earthquake of September 18, 2011 (M_w 6.8) and Delhi earthquake of March 5, 2012(M_w 4.9). Sikkim earthquake was recorded at 13 locations of the network while Delhi earthquake at 21 locations. Fig. 4 shows the time history and response spectra at Cooch Vihar station (PGA= 0.058g) for Sikkim earthquake while Fig. 5 shows time history and response spectra at Ridge observatory (PGA= 0.0026g) for Delhi earthquake.

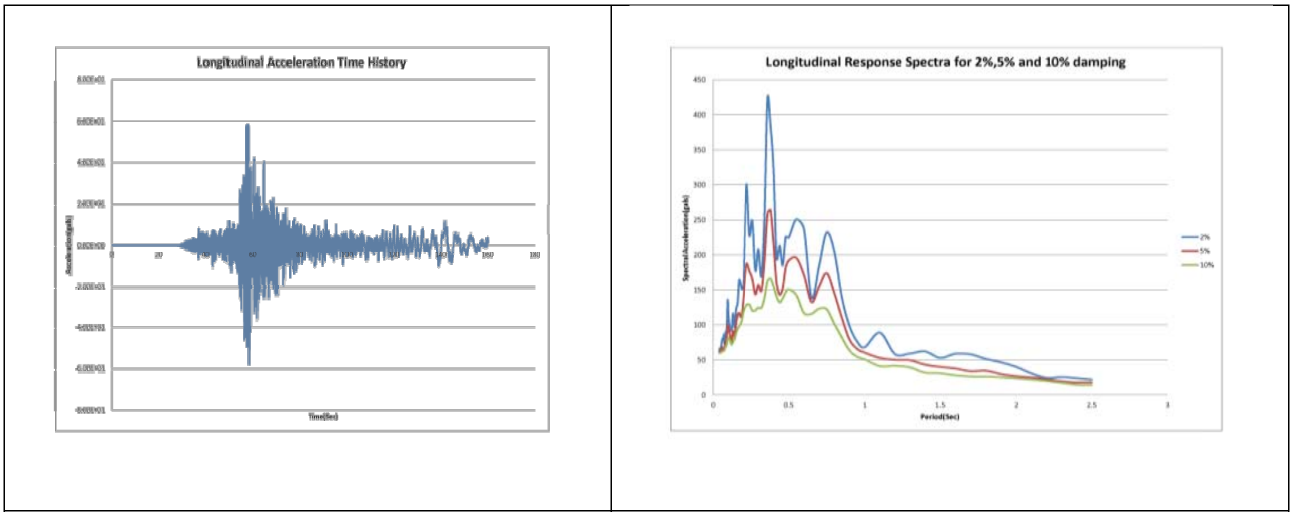

Figure 4. Time history and response spectra for Sikkim earthquake at Cooch Vihar station

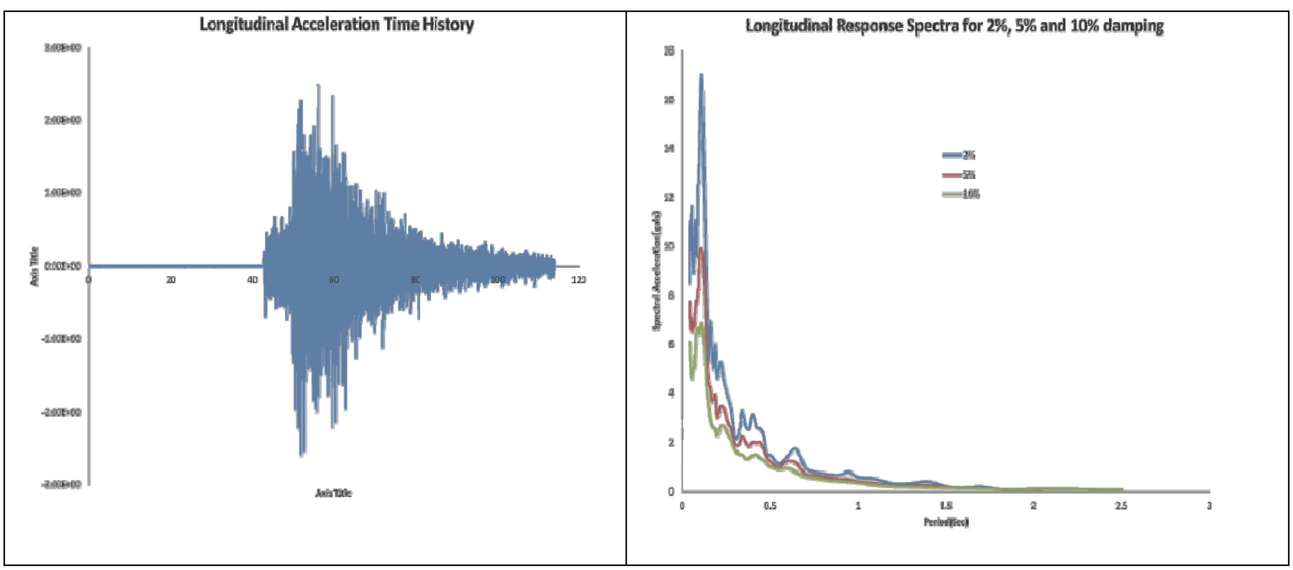

Figure 5. Time history and response spectra for Delhi earthquake at Ridge observatory, New Delhi

8. INDIAN OCEAN TSUNAMI WARNING SYSTEM

The Indian coastal areas are vulnerable to the tsunamis generated by earthquakes from the two potential source regions, the Andaman-Nicobar-Sumatra Island Arc and the Makran Subduction Zone. The Indian Ocean Tsunami of December 26, 2004, generated by great M_w 9.3 Sumatra, Indonesia earthquake brought heavy destruction and loss of life in Indian coastal areas. With the aim for disaster reduction from future tsunamis likely in Indian Ocean, Govt. of India has established a Indian Ocean Tsunami Warning System (IOTWS) which has been operational since September 2007. The functionality and reliability of IOTWS has been tested during some earthquakes occurring in this region including the recent 8.6-magnitude earthquake which occurred on April 11, 2012 centered at a depth of about 33 km beneath the ocean around 495 km from the provincial capital of Banda Aceh, off Sumatra, Indonesia.

The IOTWS comprises of seismic systems, bottom pressure recorders, tidal gauges, coastal radars and warning centre supported by robust communication infrastructure. A database of pre-run scenarios for travel times and run-up height has been created using Tsunami N2 model. At the time of event, the closest scenario is picked from the database for generating advisories. The information on sea level data enables confirmation or cancellation of a tsunami warning. Tsunami bulletins are then generated based on decision support rules and disseminated to the concerned authorities for action, following a standard operating procedure. The Tsunami Warning Centre has successfully monitored and reported more than 200 earthquakes of larger than 6.0 magnitude to date (Nayak, 2012).

A tsunami watch was issued for countries across the Indian Ocean after a 8.6-magnitude earthquake occurred centered at a depth of about 33 km beneath the ocean off Indonesia around 495 km from the provincial capital of Banda Aceh., off Sumatra, Indonesia, on April 11,2012. It triggered widespread panic among residents. The tsunami alert issued by IOTWS immediately after the earthquake was withdrawn later after reassessment of tsunami parameters.

9. SEISMIC VULNERABILITY ASSESSMENT

9.1 Vulnerability Atlas of India

With a paradigm shift from post-disaster relief measures to pro-active pre-disaster preventive measures By Govt. of India in dealing with natural disasters, a Vulnerability Atlas of India was published by Building Material and Technology Promotion Council (BMTPC), Ministry of Housing and Urban Poverty Alleviation, Govt. of India in 1997, and the same has been revised in 2006. The revised Vulnerabilty Atlas of India gives State wise hazard maps and district wise damage risk tables for India as a whole. The information and data given in the Atlas is extremely useful for preparing damage scenario in individual recurrence of Hazards and for developing methodologies for mitigation and presentation (BMTPC , 2006).

The Vulnerability Atlas contains the following information for each State and Union Territory of India:

i) Seismic hazard map
ii) Cyclone and wind hazard map
iii) Flood prone area map
iv) Housing stock vulnerability table for each district, indicating for each house by wall and roof type, the level of risk to which it could be subjected sometime in the future.
v) The landslide hazard maps are given for three such major regions.

This atlas is now being upgraded by BMTPC to extend it to District /subdivision level within each State.

9.2 Vulnerability Assessment Studies

The Department of Earthquake Engineering in collaboration with NORSAR, Norway has developed a methodology (Prasad et al., 2009) to estimate seismic risk for communities where building vulnerability functions and inventory is not readily available. Intensity scales (MSK, EMS, and PSI) have been used to define damage probability matrices (DPMs). These DPMs can be used to estimate risk in absence of more reliable vulnerability functions. A stratified random sample survey methodology based on socio-economic clustering (Prasad et al., 2009) has been developed to efficiently generate building inventories in typical Indian urban scenario. The methodology has been applied to the Himalayan city of Dehradun.

Vulnerability functions using the capacity spectrum approach of HAZUS have also been developed for the typical Indian masonry (non-engineered) buildings and Indian code designed RC buildings (Haldar and Singh, 2009). These vulnerability functions along with some others from the literature have been implemented in a software to make analytical estimate of seismic risk for Dehradun city and have been compared (Lang et al., 2012) with those obtained using Intensity based approach.

Seismic vulnerability and risk assessment of Gandhidham city and some installations in coastal regions of Gujarat have been carried out by Institute of Seismological Research, Gujarat

9.3 Earthquake Probabilistic Loss Model

An earthquake probabilistic loss model of entire India, which is capable of estimating average annual and return period losses to insurance portfolios at State, District and City levels has been proposed by Gupta (2007). The basic framework of the model consists of five modules, namely, stochastic event, Hazard, Exposure, Vulnerability and Financial modules. The model is calibrated and validated against historical event losses and can be used by insurance and re-insurance companies for upcoming renewals

10. SEISMIC BASE ISOLATION

Seismic base isolation is one of the most popular means of protecting a structure against earthquake forces by substantially decoupling a superstructure from its substructure resting on a shaking ground. In India, the base isolation technique has been applied to few selected buildings in seismic zones IV & V on experimental basis including the construction of three buildings in Delhi by the Govt. of Delhi (Govardhan et al., 2009). Dubey et al. (2008) constructed and studied the characteristics of base isolated buildings in comparison with the conventional fixed base G+2 building at Guwahati in Northeast region. Govardhan et al.(2011) have designed and developed a laminated lead rubber bearing for a complex building at NOIDA, India and testing has been carried out at Department of Earthquake Engineering, IIT Roorkee. Stochastic response of building frames isolated by lead-rubber bearings has been studied by Jangid (2010).

11. EARTHQUAKE INDUCED LANDSLIDE HAZARD ZONATION

Himalayan region had experienced many landslides in the recent past. A recent Sikkim earthquake (September 18, 2011) triggered many landslides in the Sikkim region, which are mainly responsible for the observed damages during the 6.8 magnitude earthquake. Landslide hazard zonation maps help in planning of developmental activities in hilly areas. Earthquake induced landslide zonation studies have been reported by different researchers (e.g., Pareek et al., 2010; Jakka, 2012; Roy et al., 2012).

12. CAPACITY BUILDING PROGRAM

After the 2001 Bhuj earthquake (M_w 7.7), the need to include appropriate components of earthquake engineering in the civil engineering and Architecture curricula became obvious. A comprehensive National Program on Earthquake Engineering Education(NPEEE) and National Program for Capacity Building of Engineers in Earthquake Risk Management (NPCBEERM) have, therefore, been launched by the Ministry of Home Affairs (National Disaster Management Division), Govt. of India, envisaging eleven premier institutes of science and technology in India as resource institutions.

13. PUBLIC AWARENESS

Indian Society of Earthquake Technology(ISET), Roorkee, National Disaster Management Authority, New Delhi and state level Disaster Management Centers are engaged in carrying out earthquake awareness programs for general public and disaster managers. Assam State Disaster Management Authority released a pamphlet about reliable seismic precursors for common man (Bapat, 2011).

14. CONCLUSION

The various measures recently taken and being implemented in India towards seismic risk assessment and risk reduction by Government of India and other institutes/agencies and individual research workers are briefly described in this paper.

ACKNOWLEDGEMENTS

The author is thankful to Dr. Arun Bapat, Prof. S.K.Nath, Prof. M.L.Sharma, Prof. Ashok Kumar, Dr. Y.Singh, Dr. M. Shrikhande, Dr. Daya Shanker, Dr. R.S.Jakka, Ms. Pallabee Choudhury, Mr. Govardhan, the Department of Earthquake Engineering, IIT Roorkee, Indian Society of Earthquake Technology, Roorkee and other researchers for providing technical information. The author is also grateful to Mr. Ranjit Das, Ph.D. Scholar for his help in the preparation of the manuscript.

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