A NEW INSURANCE LOSS MODEL TO PROMOTE CATASTROPHE INSURANCE MARKET IN INDIA AND PAKISTAN

M.R. Zolfaghari [1] and K.W. Campbell [2]

[1] *EQECAT, ABS Consulting, London, United Kingdom, mzolfaghari@catrisks.com*
[1] *EQECAT, ABS Consulting, Oakland, United States, kcampbell@absconsulting.com*

ABSTRACT:

Catastrophe loss modelling has been under rapid development in the recent years. This is mainly due to significant demands for natural catastrophe models and their applications in the financial and insurance industry. Computer risk models today are used to evaluate potential losses from future events and provide facilities for better controlling exposure to potential losses. The first generation of earthquake loss model for India subcontinent was developed in the late 1990's and has been used by many insurance and reinsurance companies for various insurance portfolio analyses. In this paper the methodology and preliminary results for a new earthquake model for this region is presented. The seismic hazard, the built environment inventory and the building vulnerabilities are probabilistically convoluted to estimate probabilistic losses. Such results once implemented in user friendly financial software, are used by insurance and reinsurance companies to estimate their potential exposure to seismic hazards. The main advantages of this model are its high resolution stochastic event set, detailed seismic model, and a range of vulnerability functions describing various building types and contents. The new model uses the latest information on regional seismotectonic to develop a new regional seismic hazard model for the Himalayan belt as well as stable Indian shield. This model benefits from a high geographical resolution for the underlying administrative units to capture detailed variation of seismic hazard and to enhance the modelling of soil effect.

KEYWORDS: India / Pakistan Seismic Hazard, Risk Modelling, Insurance Loss Models

1 INTRODUCTION

The deaths, injuries, and devastation caused by two large earthquakes in recent years brought sharply into focus the seismic hazard faced by India and Pakistan. The major Bhuj earthquake of 26 January 2001 (Mw 7.6) in India caused devastation to the state of Gujrat, killing about 20,000 persons and injuring many more (e.g. Hough *et al*, 2002). It was India's most deadly earthquake in recorded history. The earthquake left nearly half a million people homeless and destroyed about 350,000 dwellings. Similar earthquake in Pakistan in 2005 caused widespread damage and loss of life to some of the remote population centers in Northern Pakistan. These earthquakes immediately raised important questions of how can seismic hazard and consequence damage to built environment and loss of lives from future earthquakes in India and Pakistan be predicted. The challenge of seismic hazard assessment in regions of diffused pattern of seismicity is how to address different seismogenic sources and their risk on the built environment.

Due to the high severity and low frequency of natural catastrophes such as earthquakes, the use of traditional actuarial methods based on historical loss records, are inadequate and incomplete for estimation of potential future losses. Computer risk models can be used to evaluate potential losses from future events and provide facilities for better controlling exposure to potential losses. Information obtained from this type of modelling is ideally suited to the regional risk consideration of traditional financial entities as well as to the growing insurance catastrophic market in the region.

The first generation of the earthquake loss models for India and Pakistan were developed in 1998 by EQECAT and have been under constant maintenance and minor modification since then. Any natural catastrophe model, regardless of the peril under study, incorporates several main components:

- Natural catastrophe hazard model
- Exposure mapping tool
- Vulnerability functions of built environment to the natural hazard
- Loss calculation and implementation of insurance conditions

A few national and regional seismic hazard studies have been performed for this region in the last decades. The first national seismic hazard map for India was compiled by the Geological Survey of India (GSI) in 1935. In 1962, a second national seismic hazard map was published by the India Standards Institution (ISI). This map was based primarily on earthquake epicenters and isoseismal maps drawn by the GSI. This map was further revised in 1966, 1970 and 1984. In 1992, the Global Seismic Hazard Assessment Program (GSHAP) was launched by the International Lithosphere Program (ILP) under the framework United Nations International Decade for Natural Disaster Reduction (Giradini *et al*, 1999). In this paper the probabilistic seismic hazard model developed by EQECAT for the Asian Continent and in particular the India and Pakistan regions is presented. In the following sections in this paper the input data and methodology applied to model seismic hazard are presented.

2 EQECAT INDIA/PAKISTAN EARTHQUAKE HAZARD MODEL

Probabilistic seismic hazard analysis provides the basic module for any seismic risk and loss model. Probabilistic seismic hazard models regardless of their use in pure engineering design purpose or for insurance loss estimation model consist of certain models. The first step in a probabilistic seismic hazard analysis is the definition of earthquake source or sources which will affect the site of interest. This step is often a major part of a seismic hazard assessment. Regional seismicity together with known tectonic features are fundamental information used to delineate seismic source zones and to determine seismicity parameters. Seismic source zones are determined based on the relationship of observed earthquakes to the tectonic manifestations of geological units. The geological and tectonic maps of Asia as a continent as well as maps with seismic interpretation such as spatial distribution of earthquake epicenters, earthquake rupture and seismic moment have been prepared as tools to delineate seismic source areas, to study the completeness of the earthquake catalogue, to determine seismic activity, and to define recurrence parameters for each seismic source. The seismicity parameters such as magnitude-frequency relationships and maximum magnitude are determined using past occurrence of earthquakes and expert judgment. The earthquake catalogue is examined for completeness within each source and the results are used to calculate the Gutenberg-Richter relationship.

*2.1 **Seismotectonic Setting of East Asia***

The Indian plate boundary in the study region is characterised by a continental collision segment along the Himalaya in the north, a complex to an oblique subduction along the Burma-Andaman arc in the east and transverse fault systems such as the Chaman fault in the northwest (Figure 1). It is now well known that the continued northward collision of the Indian plate with respect to the Eurasian landmass causes the intense seismicity, and has produced the most gigantic topographic features of the world, the Himalaya and the Tibetan plateau. The broad tectonic and seismicity patterns of these regions and the corresponding seismic source zones are described here.

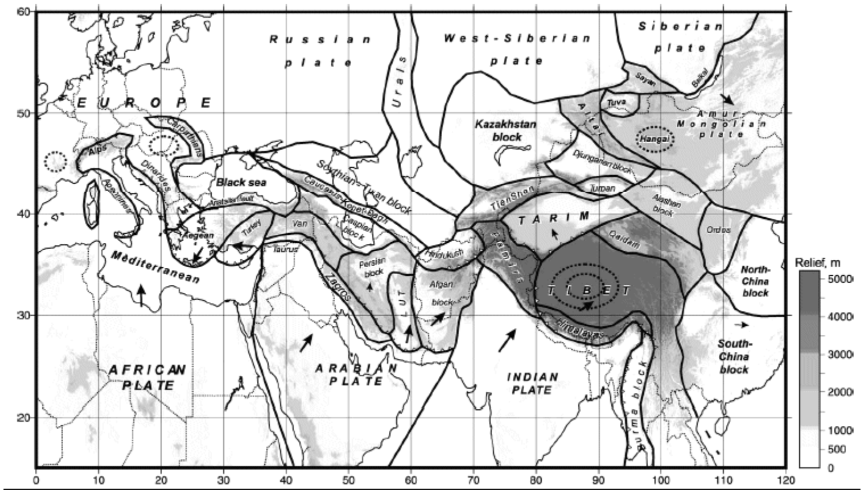


Figure 1 Surface topography and generalized structure of the Alpine-Himalayan belt. Direction of plate motion is schematically shown by arrows (after Koulakov *et al*, 2002).

The Himalayas form a clearly defined arcuate zone of plate consumption along which the Indian and Asian plates collide at the rate of about 5.5 cm/yr (Minster and Jordan, 1978). The 2400 km long east-west stretch of the Himalaya is composed of several north dipping thrust sheets which are also punctuated by topographic breaks. The major tectonic features in this region include, from south to north, the Main Boundary Thrust (MBT), the Main Central Thrust (MCT) and the Indus Tsangpo Suture Zone (ITSZ). Most of the seismicity in the Himalayan region is concentrated along shallow north dipping planes, which indicate underthrusting of the Indian plate beneath the Eurasian plate. In addition to four great earthquakes of magnitude exceeding 8 during 1897, 1905, 1934 and 1950, another 11 earthquakes exceeding magnitude 7.5 have occurred in the Himalayan belt during the past 110 years. The four great earthquakes (Ms ≥ 8.4) which have occurred along the Himalaya front during the last 110 yr left three major gaps between them. The Assam earthquakes of 1897 and 1950 rank among the few greatest continental earthquakes (M = 8.7) (Richter, 1958).

North and northeast India, including several mega-cities in the Indo-Gangetic plain, are potentially exposed to high seismic hazard from the large/great earthquakes along the Himalayan arc. It has been suggested that much of the arc may be overdue to rupture in large/great earthquakes (*e.g.* Bilham et al., 2001). Khattri (1999) has estimated the probability of occurrence of a great Mw 8.5 earthquake in the central seismic gap of the arc (a segment that extends from about 78_ E to 85_ E) in the next 100 yr to be 0.59.

Generally speaking, the Indian shield region can be considered as one single seismic source zone for hazard computations. However, smaller seismic zones can be delineated in this region, primarily based on the locales of the major earthquakes and seismic lineaments, some of which are not so well defined. The Indian shield region is marked by several rift zones and shear/thrust zones. Although considered to be a stable continental region (SCR), this region has experienced many earthquakes of magnitude Mw 6.0 since the 18th Century (Ramalingeswara Rao, 1998), some of which were disastrous. Among them are the Mahabaleshwar (1764), Kutch (1819), Damooh hill (Near Jabalpur, 1846), Mount Abu (1848), Coimbatore (1900), Son-Valley (1927), Satpura (1938), and Jabalpur earthquake of May, 1997.

The Narmada-Son lineament (NSL), a prominent tectonic feature of the Indian shield region, has been experiencing earthquakes of different magnitudes in the past, the recent example being the May 21, 1997 Jabalpur earthquake of magnitude 6.0. This is an SCR earthquake with an unusual focal depth of about 30 km. At least 4 earthquakes of magnitude >5.4 have occurred along this zone, two of them in the proximity of the 1997 Jabalpur earthquake (Gupta *et al.*, 1997). The major tectonic constituents in the southern sector of the

Indian Shield include the massive Deccan Volcanic Province (DVP), the South Indian Granulite Terrain (SIGT), the Dharwar craton (DC), the Cuddapah basin (CB), the Godavari graben (GG) and the Mahanadi graben (MG), the Eastern and the Western ghats on the east and west coast of India, respectively. The Koyna reservoir region has been experiencing induced earthquakes right from the date of its first filling in 1962. Over the past 36 years the region around the reservoir has experienced 10 earthquakes of magnitude ≥ 5, over 100 earthquakes of magnitude ≥ 4 and about 100,000 of smaller magnitudes.

In addition to seismicity associated with the Himalayan belt, there are also intraplate seismic activity threatening major cities and population centers in Indian Shield. The Mw 7.6 Bhuj earthquake of 26 January 2001 was arguably the largest intraplate earthquake to have occurred globally in more than 100 years. The Bhuj earthquake occurred far from the edge of the Indian plate and quite close to an M 7.7 earthquake that occurred in 1819 (Bilham, 1998). The Earthquake in the Government estimates place direct economic losses due to the earthquake at 1.3 billion dollars, although more recent estimates indicate losses as high as 5 billion (Hough *et al*, 2002). The location of Gujarat is over 400 km from the nearest plate boundary in central Pakistan, however, several large historical events have occurred in the region, including the Allah Bund earthquake of 1819, which was likely of comparable size to the 2001 event (Bilham, 1998, Hough *et al* 2002). Nevertheless, the repeat time for earthquakes the size of the Bhuj event is likely to be 1000 years or more, and these considerations have led parallels to be drawn between the Bhuj earthquake and the 1811–1812 New Madrid earthquake.

The northern Baluchistan region of Pakistan includes the Chaman fault system, a left-lateral transform plate boundary that separates the Indian and Eurasian plates. The Chaman fault is an 800 km long left-lateral strike-slip feature that appears south of the Herat fault and then trends south-southwest along the Afghanistan-Pakistan border (Wellman 1966). The northern Chaman fault system in the past century has been largely inactive, suggesting that this time period is not representative of long-term activity in the region and that up to 4 m of potential slip is currently available to drive one or more future M7 earthquakes.

The Eurasian plate, at its boundaries and within has a number of predominant strike-slip features. The Heart fault is a distinct morphological feature that traverses almost the entire length of northern Afghanistan for 1,100 km (Wellman 1966). According to Quittmeyer and Jacob (1979) this is a right-lateral strike-slip feature with a probable history of movement throughout the Cenozoic. Quittmeyer and Jacob (1979) believe the fault to be 'inactive' with no evidence of fault-related seismicity. Ambraseys and Bilham (2003) state that slip on this fault would be insignificant in accommodating the north-south convergence thus explaining absence of seismic activity during the historic and instrumental period. Verma *et al* (1980) have concluded that the Herat fault is seismically inactive barring its portion that trends northeast towards the Himalaya.

The Iran-Afghanistan border, coincidentally, is the eastern extremity of the Arabia-Eurasia collision zone. Walker and Jackson (2002) state that at this longitude nearly all the Arabia-Eurasia convergence (~40 mm/year at 60° E) is accommodated in the seismic belts of the Alborz and Kope Dagh in northern Iran, requiring the comparatively aseismic central Iran to move N-NNE relative to Afghanistan. The N-S right-lateral shear component between central Iran and Afghanistan is taken up by a series of N-S trending right-lateral strike-slip faults bordering the relatively aseismic Kavire Lout block. On their northern end, these faults terminate in a series of E-W trending right-lateral strike-slip faults and the Tabas thrust system while on the southern end, they terminate in the E-W coastal ranges of the Makran where the Arabian Sea is subducted northwards (Walker and Jackson (2002).

An active zone of subduction is produced in the Makran region of south Pakistan and southeast Iran where the Arabian Sea floor is subducting at a shallow angle to the north (Quittmeyer and Jacob 1979). Intense earthquake activity is reported here at depths of 70-300 km. The Arabian Sea is currently going under continental Lut and Helmand blocks with an azimuth of N10° E and with a convergence velocity of 36.5 mm/yr in the western, and 42.0 mm/yr in the eastern boundaries (Jacob and Quittmeyer, 1979; DeMets *et al*., 1990; Byrne *et al*., 1992). Except for the great earthquake of 1945 (Ms=8.1), few moderate to large earthquakes are known to have occurred in the Makran and the seismic behaviour of the Makran Subduction Zone is still largely unknown. However, most of the events which have occurred in the Makran are of intermediate depths, within the downgoing plate or along the boundary between eastern and western Makran (Byrne *et al*., 1992). A number of intermediate-depth earthquakes within the downgoing plate, form the seismicity in the western Makran at around 400-500 km away from the deformation front. The only large earthquake in the Makran following the great earthquake of 1945, is the 1983 earthquake (Figure 2), for which fault plane solution shows a predominantly normal faulting mechanism (Laane and Chen, 1989).

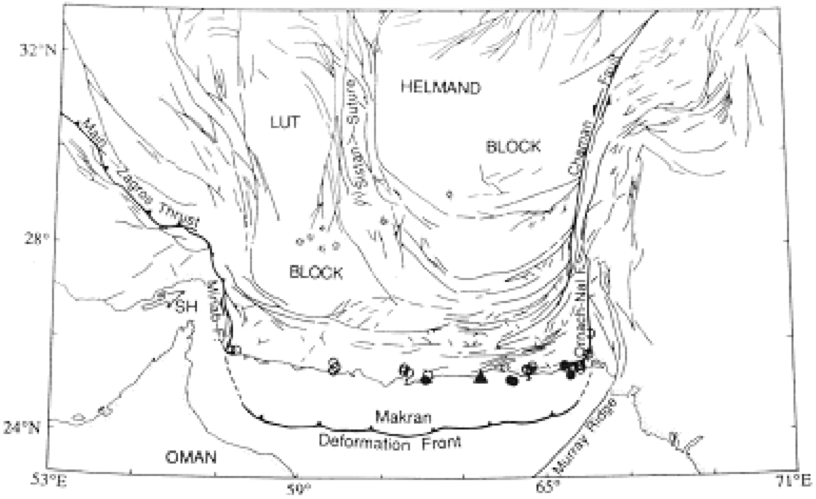
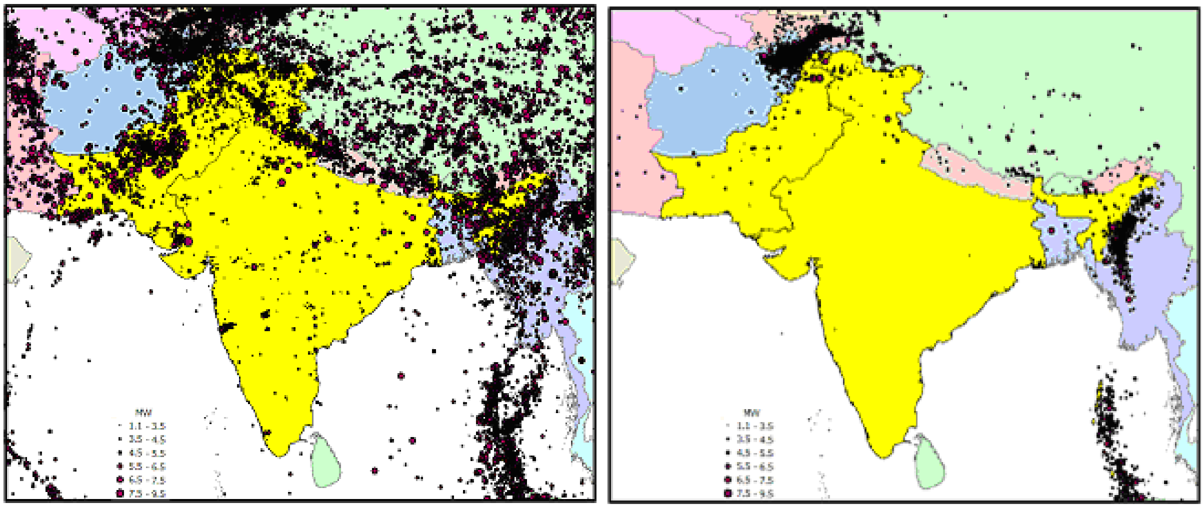


Figure 2 Major tectonic features of the Makran subduction zone. The epicentre of the 1945 great earthquake is shown as a solid triangle (Byrne *et al*., 1992).

2.2 *Historical earthquake catalogue*

Seismicity in the northern and northeasteren India and Pakistan in is mostly characterized by Active Plate tectonic Boundary features along the Himalayan belt and intraplate activity in the India shield. An earthquake catalogue was compiled for this region using regional historical as well as instrumental earthquakes. The catalogue was homogenised in terms of magnitude scale using moment magnitude Mw. The catalogues have been combined and processed in order to remove the duplicated events using an automated as well as a manual checking. The compiled catalogue is believed to be free of any duplicated events. The compiled catalogue refers to almost 20,500 earthquakes (Mw≥3.0) from 250AD to the end of 2006.

The compiled earthquake catalogue consists of all the reported historical and instrumental earthquakes. There are a large number of dependent shocks, in particular aftershocks, in this catalogue. The removal of aftershocks for a catalogue of such size requires an automated process with some pre-defined setting. The de-clustering process for the earthquake catalogue in the study area resulted in almost 15,700 main shocks with Mw≥ 3.0. These earthquakes were further used for processing the time and space distribution of seismicity in this region. Seismicity in most parts of this region is dominated by shallow thrust and strike-slip faulting at depths of less than 50 km. However, there are several regions in which intermediate depth as well as deep seismic activity is observed. The seismicity in the Himalayan belt for example has to be modelled by shallow as well as intermediate depth seismic source. Figures (3a and 3b) show the distribution of shallow (h≤70 KM) and deep (H>70 KM) respectively.



a b

Figure 3 Distribution of historical earthquakes a) shallow (h≤ 70 KM) b) deep (h>70 KM)

2.3 ***Seismic Source Modelling***

A new set of seismic sources are developed based on relationship between historical seismicity and large scale tectonic processes. The seismicity of this region including historical and recent earthquakes are combined and used as an earthquake database. Geographical and temporal distribution of past seismicity is investigated in order to define the relationship between historical seismicity and active tectonic features. The region understudy here covers a vast range of seismotectonic environments ranging from gigantic plate boundaries on the Himalayan Belt, intraplate seismic activity in the Indian Shield, several great strike-slip fault systems in Afghanistan and Pakistan and an active subduction zone in Makran. Two seismic source layers representing intermediate depth and shallow crsutal seismic sources are modelled. The shallow-depth source model refers to 75 seismic sources. The intermediate-depth source model refers to 11 seismic source zones representing the deep events in the Himalayan and eastern India. Theses sources provide necessary geographic coverage for India and Pakistan. Average focal depths are also estimated based on the observed focal depth for events in each source. The compiled earthquake catalogue had been assembled from several national, regional and international sources. Therefore the homogeneity of the earthquake catalogue from both spatial and temporal points of view is of great concern which needed further investigations. The statistical method proposed by Stepp (1972) was used for the completeness test which provides estimate of time periods over which earthquakes are recorded completely. Exponential and combined characteristic-exponential relationships (Schwartz and Coppersmith, 1984) were used to model the frequency-magnitude distributions.

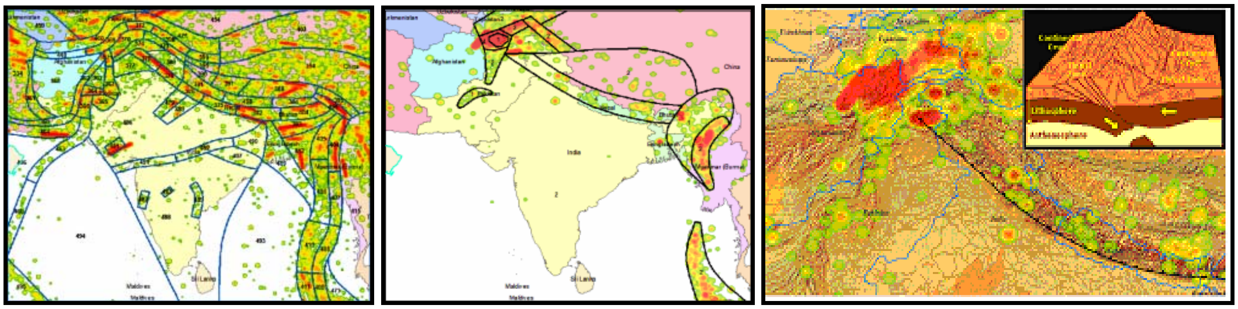


Figure 4 Seismic source models representing shallow and intermediate depth earthquakes versus spatial distribution of seismic moment released by historical earthquakes

3 PROBABILISTIC SEISMIC LOSS ESTIMATION

Insurance catastrophe modelling tools estimate probabilistic earthquake losses to insurer's portfolio based on ground motions generated from a range of probabilistic events with various magnitudes and frequencies. Every event in this process acts like a scenario with a given frequency, representing the regional seismological severity and frequency. To model this part, the seismotectonic setting introduced for this region has to be converted to a synthetic earthquake set in which each event acts like a real earthquake with size, location and frequency. This event set provides synthetic earthquakes on a regular grid point of a chosen resolution and includes all events produced by seismogenic sources and in the vicinity of the modelled areas. Using the stochastic earthquake event set and the ground-motion model (attenuation relationships, soil amplification factors and their associated variability), a probabilistic distribution of ground motions for each hazard point is calculated. The monetary damages to each risk or group of risks within the imported portfolio are calculated using mapped vulnerability functions and insurance policy conditions such as deductible and limits.

Physical damage to structures during earthquakes could be produced by various agents of seismic hazards. Ground shaking produces scattered but widespread damage, and the effects of strong ground shaking are responsible for a large portion of building damage in most countries in Asian region. EQECAT's vulnerability functions used for damage calculation are based upon extensive field investigation of over 100 earthquakes and windstorm events and the use of billions of dollars of insurance claim data. EQECAT building vulnerability functions are specific to each country and region based upon engineering knowledge of local building codes and practice. Damage functions are sensitive to variables such as building materials and structural systems, building height, age, and occupancy type.

The loss model developed for the study region can import users exposure data based on several geographic resolutions such as CRESTA zones, postcode units and site specific location specified by longitude/latitude. Country and CRESTA aggregated data gets further disaggregated into finer resolution based on disaggregation module built into the model. To calibrate the vulnerability functions and also test the validity of the loss results, the model was used to simulate losses from some of the historical earthquakes. Some of the damaging events in the 20th century were used for this purpose.

4 CONCLUSION

Natural catastrophe loss modelling has been under rapid development and use by insurance and reinsurance companies in the last two decades. These tools play important rules in the assessment of potential financial losses to insurance portfolios. They provide assessment for the necessary risk transfer and capital that an insurance or reinsurance company may need for its safe operation. The development and application of catastrophe risk model for developing countries allow for the design of sound property insurance solutions for better risk sharing between households, local insurers and international reinsurers. In this paper, the EQECAT's new earthquake loss model for India and Pakistan is briefly introduced. Since its development in 2006, the model has been used by many insurance and reinsurance companies worldwide. This model is capable of estimating seismic losses for different types of buildings by usage, structural types and occupancies. Probabilistic loss curves as well as annual mean losses can be estimated using this model. The model compared to its earlier version, provides much higher geographical resolution both in terms of hazard calculation and loss estimation. Application of this tool on a national scale by domestic insurance companies could help insurance market in these countries to rationally quantify their status with regard to catrisk insurance rate, catrisk policy terms based on risk pricing and homeowner affordability, risk mitigation, healthy insurance penetration, risk-based premium, national awareness, catastrophe insurance law and many other insurance related factors.

REFERENCES

Ambraseys NN, Bilham R. (2003). Earthquakes in Afghanistan. *Seismological Research Letters*; **74**; 107-123.

Bilham, R. (1998). Slip parameters for the Rann of Kachchh, India, 16 June 1819, earthquake, quantified from contemporary accounts, in Coastal Tectonics, I. S. Stewart and C. Vita-Finzi (Editors), *Geological Society London Special Publications*, London, 146, 295–318.

Bilham, R., and England P. (2001). Plateau pop-up during the great 1897 Assam earthquake, Nature 410, 806–809. magnitudes, *Bull. Seism. Soc. Am*. **66**, 1501–1523.

Byrne, D.E., L. Sykes, and D.M. Davis, (1992). Great thrust earthquakes and aseismic slip along the plate boundary of the Makran subduction zone*, J. Geophys. Res.* **97**, no. B1, 449-478.

De Mets, C., D.F. Gordon and S. Stein (1990). Current plate motions, Geophys. J. Int.101, 425-478.

Giardini, D. Grünthal, G. Shedlock, K. and Zhang P. (1999). Global seismic hazard map, Global Seismic Hazard Assessment Program (GSHAP), UN/International Decade of Natural Disaster Reduction

Gupta, H.K., Chadha R.K., Rao M.N., Narayana B.L., Mandal P., Kumar R. M. and Kumar N., (1997) The Jabalpur earthquake of May 22*, Jour. Geol. Soc*. India**, 50**, 85-91.

Hough S. E., Martin S., Bilham R., and Atkinson G. M. (2002). The 26 January 2001 M 7.6 Bhuj, India, Earthquake: Observed and Predicted Ground Motions. *Bulletin of the Seismological Society of America***, Vol. 92, No. 6**, 2061–2079

Koulakov I, Tychkov S, Bushenkova N, Vasilevsky A. (2002). Structure and dynamics of the upper mantle beneath the Alpine-Himalayan orogenic belt, from seismic tomography." *Tectonophycics*; **358: 77 – 96.**

Laane J. and W.P. Chen (1989). The Makran earthquake of 1983 April 18: A possible analogue to the Puget Sound earthquake of 1965?, *Geophys. J. Int*. **98**, 1-9.

Minster, J. B. and T. H. Jordan (1978). Present-day plate motions, *J. Geophys*. *Res***. 83**, 5331.

Richter, C. F. (1958). Elementary Seismology, W. M. Freeman & Company, San Francisco, 768 pp.

Murakawa, H., Ueda, Y. and Xiang, D. (1995). Effect of fluid force acting on colliding body upon damage given to offshore structures. *Journal of Constructional Steel Research* **33:3,** 259-281.

Quittmeyer RC, Jacob KH (1979). Historical and modern seismicity of Pakistan, Afghanistan, NW India and SE Iran. *Bulletin of the Seismological Society of America* **69(3**): 773-823.

Jacop, K.H. and R.C. Quittmeyer (1979). The Makran of Pakistan and Iran: trench-arc system with active plate subduction, Geodynamics of Pakistan, *Geol. Surv. Pakistan*, 305-317.

Schwartz, D.P. and K. J. Coppersmith (1984). Fault behaviour and characteristic earthquakes: examples from the Wasatch and San Andreas Fault Zones, *J. Geophys. Res***. l 89, no. B7**, 5681-5698.

Stepp, J.C. (1971). An investigation of earthquake risk in the Puget Sound area by use of the type 1 distribution of largest extremes, Pennsylvania State Univ., Ph.D. Thesis in Geophysics.

Verma RK, Mukhopadhyay M, Bhanja AK (1980). Seismotectonics of the Hindukush and the Baluchistan arc. *Tectonophysics* **66**: 301 – 322.

Walker R, Jackson J. (2002). Offset and evolution of the Gowk fault, S. E. Iran: A major intra continental strike slip system*. Journal of Structural Geology*; **24:** 1677-1698.

Wellman HW. (1966). Active wrench faults of Iran, Afghanistan and Pakistan." *Geological Review* (Geologische Rundschau) **55**: 716-735.