Estimating Pre-Seismic Peril for Middle and South India

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ABSTRACT

This manuscript present probabilistic pre-pre-seismic peril evaluation of south middle India (south of 28° N), and which is characterized by crustal inter plate pre-seismic activity in craton and rifting zones. It also brings more than a few updates including: 1) peril evaluation in middle India 2) estimating resource zone-specific pre-seismicity parameters, 3) use of more than a few recently obtainable GMPEs both in terms of PGA and SA at dissimilar frequencies for incorporating the unpredictability in the ground movement for pre-seismic peril associated with dissimilar zones in middle and south India.

***Keywords*:** Pre-seismic peril, Probability, Logic Tree, Gridded Pre-seismicity.

I INTRODUCTION

In a previous study, the authors have developed probabilistic pre-seismic peril map in terms of peak ground accelerations incorporating spatial characteristics of pre-seismic resource zones of peninsular India (south of 28° N). More than a few combination models that are uniform, background, geo-based and reservoir induced pre-seismicity to capture epistemic uncertainties in the pre-seismic peril (Jaiswal 2006, Jaiswal and Sinha, 2007). In the present investigation we estimate pre-seismic peril extending resource zones further to North India (south of 32° N) but excluding foothills and Himalayan belt in north, highly pre-seismic north-eastern part and Hindukush region in northwest as most of these belongs to either inter-plate or continental-continental thrust, extended margins or plate boundary area. Such area need to be modelled with additional constraints such as knowledge of tectonic domain, accurate delineation of faults, pale pre-seismic and geologic investigation to understand active faults and their mechanism slip rates and rupture properties and is beyond the scope of this investigation. Middle and south India covers more than 50% of the country and approximately 50% of country's 1.1 billion population lives in this region. The mainly current version of pre-seismic zoning map of India obtainable in building design codes (IS 1893: 2002) has not measured detailed pre-seismic peril analysis of the region using moreover deterministic or probabilistic approaches, rather it is based on limited earthquake catalogue data, pre-seismic of large historical earthquakes and limited analysis (Krishna,1992). More than a few researchers have highlighted the issue of urgent upgrade of existing pre-seismic zoning map of India (Jain and Nigam, 2000, and Khattri, 2006) in the wake of recent earthquake disasters (Latur 1993, Jabalpur 1997, Chamoli 1999, Bhuj 2001 and Kashmir 2005) which has resulted in the death of over 20,000 people in India and left millions homeless and causing enormous impact on regional and country's economy.

II METHODOLOGY

We make use of gridded pre-seismicity move toward proposed by Frankel (1995) and has been used generally for the estimation of pre-seismic peril in Middle and Eastern United States (CEUS) region as a division of national pre-seismic peril maps in 1996, 2002 and the most recent 2008 revision (Petersen et al., 2008). The come within reach of is particularly appropriate for modelling craton and rift zone exact pre-seismicity in stable continental area of peninsular India (Jaiswal, 2006). Probabilistic pre-seismic peril evaluation consists of: a) establishing seismic reappearance activity in each grid cell or resource using earthquake directory data and developing magnitude-frequency relations (Gutenberg-Richter parameters *a* and *b*-values), and estimating pre-seismicity rates for each grid cell or resource, b) determining resource-specific (grid cell, fault or area resource) maximum magnitude potential, c) estimating ground shaking at site or grid cell from each of the earthquake resource-specific earthquake along with its associated rate and developing peril curve, d) estimating ground movement at a site or grid cell for certain predefined exceed levels (e.g., 10% or 2% probability of exceed in 50 years, corresponding to an average recurrence of ~475 or ~2500years, respectively), and e) developing pre-seismic peril map in terms of peak ground parameters (accelerations, velocities) and pseudo spectral accelerations at dissimilar frequencies (3 and 5 Hz). Supplementary information about probabilistic pre-seismic peril evaluation can be originated at other literature (for example, Cornell, 1968, Frankel, 1995, McGuire, 2004).

III GEOLOGIC ZONING AND PRE-SEISMICITY

Stable continental area are often characterized by short history of macro or micro pre-seismic data and limited knowledge in terms of active tectonic features and thus remain area of wonders in terms of future pre-seismic activity. Reactivation of inactive pre-seismic resource or production of earthquakes from original unguided pre-seismic resource in steady protect masses has frequently caused revelation earthquakes (for example, Latur earthquake of 1993).

However, it is obvious that pre-seismic peril linked with SCRs is significantly lesser than active tectonic area such as Himalayas in the north, Hindukush northwest and Andaman region in the eastern part (Figure 1). Seeber et al. (1999) proposed pre-seismic scheme for peninsular India while estimating the pre-seismic peril for the state of Maharashtra in India. We slightly modify the original zoning by spatially mapping the various tectonic settings in the region, covering broad geologic feature within zone (for example, extending Narmada Lineament further to the west, straightening and expansion of western unreceptive edge to east, extending eastern unreceptive margin zone further northeast, etc.) and including additional north-western area to better characterize pre-seismic peril associated with western part of upper craton (NC) zone. It is clear that the elevated pre-seismic movement linked with upper part of India further north to the border of Upper Craton is not included in estimating pre-seismicity parameters potentially owing to unlike tectonic domain and settings. Clearly it will result in underestimation of pre-seismic peril for Upper Craton. Pre-seismic peril associated with Himalayan belt will most likely dominate in this region.

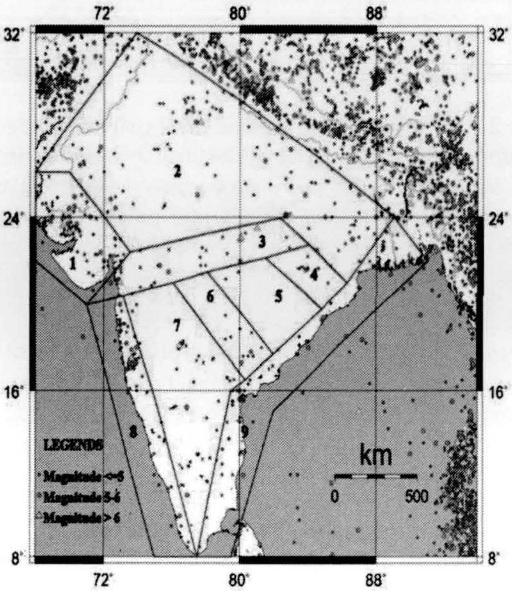


Fig 1. Pre-seismic activity in India and adjoining area

The nine broad pre-seismic zones are: 1) Rann of Kutch (ROK), 2) Upper Craton (NC), 3) Narmada Lineament (NL), 4) Mahanadi Graben (MG), 5) Eastern Craton (EC), 6) Godavari Graben (GG), 7) South Craton (SC), 8) Western Passive Margin (WPM), and 9) Eastern Passive Margin (EPM).

The information specific to the geologic and tectonic characteristics of each pre-seismic zone, their historic and recent pre-seismic activity can be found at Jaiswal (2006). whole until 2002 for peninsular India to receive earthquakes in upper part of India (south of 32° N) and extending it in anticipation of the year 1600 via Bapat et al. (1983) which covers information from 1459, GSHAP earthquake directory by Bhatia et al. (1999) and toting up the majority current activity until the year 2005, from NEIC Preliminary Determination of Epicentres (PDE) data (NEIC 2007). The raw data has been processed by removing foreshock and aftershock data and then converting it into moment magnitude using the procedure described in Jaiswal (2006). Figure 1 illustrates the epicentres of historical pre-seismic activity associated with India and adjoining area between the years 1600 to2005.

IV GROUND MOVEMENT EQUATIONS

Due to the lack of well-defined ground movement prediction equations for the region, we used four crustal intra-plate relationships, which include two simulation-based relationships for Middle and Eastern United States (CEUS). Both Eastern North America and Peninsular India area share similar features in terms of observed seismogenic activities and known seism tectonics, as discussed by Schweig et al. (2003) and Cramer and Kumar (2003). We have used newly developed ground movement equations for Middle and Eastern North America and weighted them based on the categories as explained below: We used Frankel et al. (1996) single corner model along with the new model developed by Toro et al. (2005) which is a single corner, extended resource model, and Atkinson and Boore (2006), a dynamic corner frequency resource model which accounts for magnitude saturation and variable stress drop and Silva et al. (2002), a constant stress drop with magnitude saturation model. The weights are assigned to solitary place restricted error representation (accounts for magnitude saturation; wt 0.25), on its own place position resource, dynamic corner occurrence sculpt (accounts for size infiltration and changeable anxiety drop, i.e., 140 and 200 bar; wt 0.125 each) and the remaining weight for a constant stress drop model by Silva et al. (2002). We have converted hard-rock attenuation relations to approximate ground movements for a site with shear velocity on the NEHRP B/C boundary using kappa (typically assumes value of 0.01). It is a single key parameter that defines the high frequency near-surface site attenuation of the ground movement. Information specific to the ground movement predictions equation used in this investigation, its distance metric and uncertainties in ground movements are discussed in detail by Petersen et al. (2008).

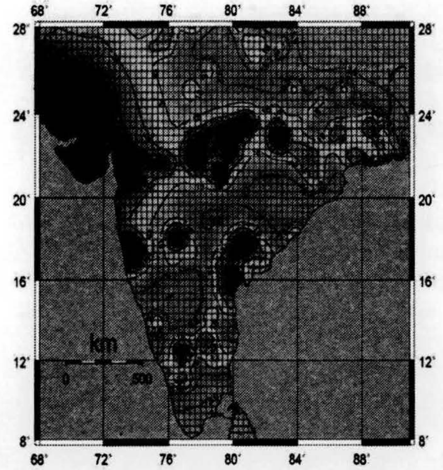
V PERIL ESTIMATION

For the application of gridded pre-seismicity approach, the entire region is divided into smaller grid cells of size 0.1° ×0.1° i.e. approx. 11 km × 11 km area. A minimum magnitude M_W = 4.5 has been chosen for the peril estimation based on the observation that earthquakes of that magnitude can be damaging to the existing vulnerable building stock (Sinha et al. 2001).

In case of gridded pre-seismicity approach, we estimate number of earthquakes greater than minimum cut-off magnitude in each grid cell and then estimate the incremental rate for each grid cell. Spatial smoothening of 50 km incorporates errors associated with epicentre locations of pre-instrumental earthquake events, catalogue incompleteness in low magnitude ranges and variability in grid patterns. The mean rate of peril at the centre of each grid is evaluated using all the *a*-values associated with all grid cells that are within the smoothening distance range (Frankel, 1995). The estimated ground movements are typically quantified in terms of a median value (a function of magnitude, distance, site condition, and other factors) and a probability density function of peak horizontal ground accelerations or spectral accelerations (McGuire, 2004). Ground movement maps have been produced by considering the ground movement distribution from each of the potential earthquakes that can affect the site and that have 2% probability of exceed in 50 years. The pre-seismic peril maps contain been ready by means of a orientation site situation that is particular to be the margin among NEHRP classes B and C, with a shear-wave speed in the higher 30 m of the outer layer of 760 m/s.

VI DEVELOPMENT OF PRE-SEISMIC PERIL MAP

The authors have earlier presented peril map in terms of 10% probability of exceed of peak ground accelerations in 50 years for peninsular India (Jaiswal and Sinha 2007). The pre-seismicity model consisted of uniform; geo-based, reservoir induced and background pre-seismicity with equal weights. We observed that the background pre-seismicity model with 25% weight considerably reduced the ground movement associated with Rann of Kutch and Narmada lineament zone. In this investigation we derive the pre-seismicity rates for each zone independently (Figure 2) from the catalogue data and then model the Gaussian smoothed pre-seismicity for each zone in such a way that the overall modelled pre-seismicity of the zone directly reflects the historical pre-seismicity rates. By using advanced Gaussian smoothening space of 51 km to extend the recorded pre-seismicity at larger space to account for errors in the epicentre place, uncertainties in the resource characterization (for example, lack of data on active vs. inactive faults within each zone). The resource of the Bhuj earthquake of 2001 was not associated with any previous large historical earthquakes and similarly the occurrence of Killari earthquake of 1993 in a region that had not experienced notable pre-seismicity in the past.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	[illegible]	[illegible]	[illegible]

Fig. 2 Probabilistic pre-seismic peril map showing peak ground acceleration peril in dissimilar zones of middle and south India for 2 % probability of exceed in 50 years using Shake Map style colour palette (Wald et al., 1999).

In Figure2 provides pre-seismic peril map for 2% probability of exceed in 50 years, i.e., corresponding to estimation of ground movement at a site in terms peak ground acceleration that have an average recurrence of 2500 years or also termed as maximum considered earthquake (MCE) ground movement. Most of the building code uses this peril value to define the pre-seismic peril and then reduce it by correction factors to estimate design basis earthquake (DBE) ground movement (i.e., ground movement corresponding to 10% of probability of exceed in 50 years or return period of ~475 years). The map shown in figure 4 indicates peak ground acceleration estimates shown using Shake map colour palette scheme that provides an interpretation from peak ground movement parameters to shaking intensity. In case of Rann of Kutch, we estimate ground movement to be much higher than peninsular India.

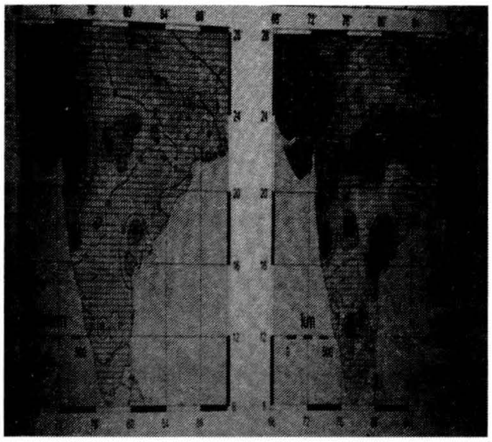


Fig. 3 Probabilistic pre-seismic peril map showing pseudo spectral acceleration at a) 3 Hz and b) 5Hz in dissimilar zones of middle and south India for 2% probability of exceed in 50 years.

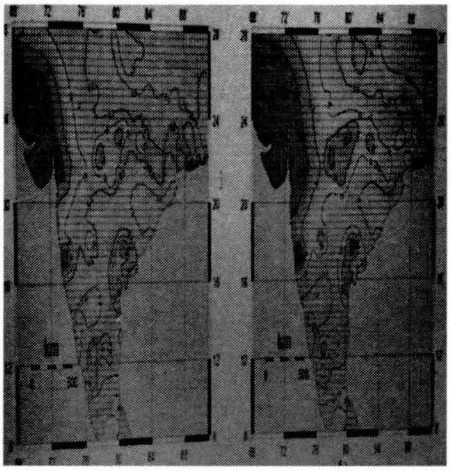


Fig. 4 Probabilities pre-seismic peril map showing a) peak ground acceleration and b) pseudo spectral acceleration at 5 Hz in dissimilar of middle south India for 10% probability of exceed in 50 years.

The higher pre-seismic peril estimates appear to be consistent with the three devastating earthquakes (M $\geq$ 7.5, shaking intensity IX and above) in this region during relatively shorter catalogue duration (e.g., 1668 earthquake that destroyed the town of Samaji, 1819 earthquake of M_W 7.7 that killed 1500 people in Bhuj and 500 in Ahmadabad; Bhuj earthquake of 2001 that killed over 13000 people). We also develop peril map in terms of pseudo spectral acceleration at 3 and 5 Hz frequencies (figure 5a and 5b, respectively), which is generally very useful to structural engineers for earthquake resistant design. The MCE stage land movement linked with Koyna area appears to be in the range of 0.66 g in conditions of PGA, that corresponds to instrumental shaking intensity VIII and above, whereas the spectral acceleration at 3 Hz ranges from 0.35 to 0.65 g. Pre-seismic peril map developed in terms of peak ground acceleration for 10% probability at 50 years (see Figure 6a) in general, indicates higher peril for Rann of Kutch which corresponds to shaking intensity IX and above. Likewise the peril linked with Narmada lineament region and eastern inert periphery ranges from 0.18 g to 0.3 g equivalent to instrumental trembling intensity VII as shown in figure 6(a). This matches the trembling intensity related with present 1997 Jabalpur volcanic activity in NL zone of Madhya Pradesh and 1969 Bhadrachalam volcanic activity in eastern Andhra Pradesh correspondingly. The plan basis land movement increases by 1 intensity entity for the 5 Hz phantom acceleration map as shown figure 6(b) in these zones.

VII CONCLUSION

The paper presents probabilistic pre-seismic peril map of middle and south India in terms of peak ground accelerations and spectral accelerations at dissimilar frequencies. Some of the important features of this study are use of more than a few newly developed ground movement prediction equations for peril assessment, re-assignments of maximum magnitude potentials to the zones, re-alignment of zone boundaries, estimation of zone specific pre-seismicity parameters and development of a peril map in terms of spectral acceleration parameters at dissimilar frequencies which would be useful for engineering applications. It is important to note some of assumptions and idealization that are inherent with this assessment, such as a) estimated historical rate of pre-seismicity will represent future pre-seismicity, b) geo-based maximum magnitude potential is applicable, c) similarity of ground movement characteristics between CEUS and peninsular India, and finally d) earthquake occurrence in peninsular India is Poisson process. Although, the investigation utilizes the 400+ years of earthquake data along with similarity hypothesis of seism tectonic characteristics elsewhere to deduce the recurrence characteristics of future earthquakes and zone-specific maximum magnitude potential, rigorous geological and pale pre-seismic studies are necessary in this area before such data could be used to constrain these parameters for future updates of the map. The newly developed pre-seismic peril map shows higher design pre-seismic forces than currently used in earthquake zoning map of India of IS code. The authors feel that it is possible to carry out further improvements in the zoning map presented in the paper based on emerging multi-disciplinary research before a definitive zoning map can be developed.

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