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Earthquake Risk Management Strategy Plan Using Nonparametric Estimation of Hazard Rate

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Abstract: Earthquake risk is defined as the product of hazard and vulnerability studies. The main aims of earthquake risk management are to make plans and apply those for reducing human losses and protect properties from earthquake hazards. Natural risk managers are studying to identify and manage the risk from an earthquake for highly populated urban areas. They want to put some strategic plans for this purpose. Risk managers need some input about these kinds of studies. The prediction of earthquake events such as a input for preparation of earthquake risk management strategy plans were tried to find in this study. A Bayesian approach to earthquake hazard rate estimation is studied and magnitudes of historical earthquakes is used to predict the probability of occurrence of major earthquakes.

Key words: Earthquake hazard rate, risk management, vulnerability, seismic loading, MCMC

INTRODUCTION

Earthquakes pose inevitable risks to everyone who lives on this planet. Even though the hazard is well recognized, no one knows when an earthquake will strike or how severe it will be. The hazards and catastrophic losses brought by recent earthquakes in some developing countries around the world accentuate the need for formulating policies and strategies in a line to minimize the risks and expected losses of earthquakes. During the June 20, 1990 Rudbar-Tarom earthquake (Mw = 7.3) in northwest Iran, more than 40,000 people lost their lives, more than 500,000 became homeless, nearly 100,000 buildings were destroyed, three cities and 700 villages were razed to the ground. The moderate (Mw = 6.6) Bam (SE Iran) earthquake of December 26, 2003 killed several thousands and demolished a city of 80,000 people located in a sparely populated area at the southwestern edge of the Lut Desert. Such great disaster occurred not only because of a large magnitude earthquake but also because of poor construction and preparation in vulnerable areas. Reconstruction of these regions was estimated to cost at least 10 billion dollars.

It is known that, approximately 20% of the world's population are living in seismically active zones. In 50 years time, half of the urban people in the world's 50 largest cities will live within 200 km of faults that are known to produce earthquakes of Richter magnitude 7 or greater[8].

Furthermore, 90% of that population will be in risk the developing countries. It is also obvious that, socio-economic development of the countries has led to increase of losses due to natural disasters like earthquake. The aims of risk management are making a project and put some strategies to reduce not only human losses but also protect properties, lifelines, etc. due to earthquakes. It is seen that, when the number of unknowns and uncertainties increases in any study, the degree of risk increases dependently[1]. It is known that, it is not easy to prepare an earthquake risk management plans of any urban area due to high number of input parameter needed. The goal of risk management is to identify the risk of the study and develop strategies to reduce them. So, the goal of risk management should be to move uncertainty away from risk and move towards opportunity[9].

Earthquake risk management methodology is composed of by the integration of two different studies. seismic hazard analysis is one of them, which provides information on engineering geology, geomorphology, tectonics, seismicity and soil conditions. Historical earthquake records are used to propose the class of prior distributions, which is the prediction of propapility of potential for ground motion. the hazard rate function is prepared in the second stage. In the last stage formulation is furnished an approximation of the posterior distribution. After obtaining the critical earthquake events, these outputs, which can be used as an input for strategy plans, some critical properties and lifelines like natural gas lines, interchanges and schools have been indicated on the map. Geographic Information System (GIS) was used for the realisation of damage and loss estimation analyse in this part of the study. It is well known that the unknown distribution of positive variables can be described in terms of its

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hazard rate function. Interest in Bayesian nonparametric hazard rate estimation dates back to the early work by Dykstra and Laud[3], who introduced the weighted gamma process-extended gamma process in their terminology as a tool for modelling prior hazard rates. Then, in the context of multiplicative intensity models, Lo and Weng were able to build an unrestricted-possibly smooth-hazard rate as the mixture of a kernel with a weighted gamma measure on an Euclidean space[6]. Eventually, James extended the framework to deal with semiparametric models and also let the measure space be an arbitrary Polish one[8]. La Rocca is shown that a Bayesian approach to hazard rate estimation, based on building the prior hazard rate as a convolution mixture of a probability density with a compound Poisson process[7].

SEISMIC HAZARD ANALYSIS

One integrated part of earthquake risk management study is seismic hazard analysis. As it is mentioned above, the degree of uncertainty increases risk value in the earthquake studies. These uncertainties are mostly found around the size, time and location of future earthquakes. Seismic hazard analyses involve the quantitative estimation of ground-shaking hazards at particular site. Seismic hazards may be analyzed deterministically, as when a particular earthquake scenario is assumed, or probabilistically, in which uncertainties in earthquake size, location and time occurrence are explicitly considered[5].

when the object is statistical analysis, an earthquake is essentially described by five coordinates: latitude, longitude and depth of its first motion, together with its origin time and the so-called magnitude, which is a measure of the event size on a logarithmic scale. Then, a suitable framework for statistical modelling is offered by the theory of point processes, which reduces to the theory of counting processes, if the analysis concentrates on the distribution of origin times. This is commonly done by fixing a suitable space-magnitude window, i.e. by only considering strong events in a given seismogenic region.

Let $0 = S_0 < S_1 < S_2 ..... < S_n < .....$ be an increasing sequence of random variables modelling the event times at issue. An equivalent representation is given by the counting process(La Rocca, 2005),

$$N(t) = \sum_{i \ge 1} \Pi_{\{S_i \le t\}}, \qquad t \ge 0 \tag{1}$$

or, alternatively, by the sequence of inter-event times $T_i = S_i - S_{i-1}, \quad i \ge 1$. A nice way to specify the distribution of N is by assuming exchangeability of the inter-event times, that is by letting N be a renewal process, conditionally on the unknown distribution of T_i. This is to be considered a reasonable assumption, if the strongest earthquakes only are at present study.

An important aim in seismic hazard analysis is the evaluation the geophysical risk, that is the instantaneous conditional expected number of events per time unit. In fact, this is nothing else than the stochastic intensity,

$$\lambda(t) = \ell\text{im}_{\Delta t \to 0} \frac{E[N(t + \Delta t) - N(t) \mid F_{t-}]}{\Delta t} \tag{2}$$

of the counting process N with respect to the observed history F_{t^-}, where F_{t^-} is the σ-algebra of events generated by $\{N(s): \quad 0 \le s \le t\}$.

Letting the inter-event times T_i, $i \ge 1$ be i.i.d. $\square\ \rho(t)\exp\left\{-\int_0^t \rho(s)ds\right\}dt$, conditionally on the unknown hazard rate ρ, as discussed above, it is possible to compute the geophysical risk (2) in what will be called the nonparametric renewal model as:

$$\begin{aligned} &\lambda(t) = \hat{\rho}_t(t - S_{N(t)}) \\ &\hat{\rho}_t(s) = h_{N(t)}(s; T_1, ..., T_{N(t)}, t - S_{N(t)}) \\ &h_n(s; t_1, ..., t_n, t_{n+1}) = E[\rho(s) \\ &\mid T_1 = t_1, ..., T_n = t_n, T_{n+1} > t_{n+1}] \end{aligned} \tag{3}$$

that is through the Bayes estimator of ρ under quadratic loss, where it is worth noting that the last observation is right censored. This result can be proven by first conditioning on ρ and F_{t^-} toghether, thus finding the well known renewal intensity $\rho(t\text{-}S_{N(t)})$, $t \ge 0$, then noting that the trace of F_{t^-} on $\{N(t)\} = n\}$ is the same as the trace on $\{T_{n+1} > t - S_n\}$ of the σ-algebra of events generated by T_1, …, T_n. In this way, Bayesian nonparametric hazard rate estimation, carried out on the inter-event times, becomes a tool for nonparametric geophysical risk evaluation.

PRIOR DISTRIBUTION

According to Ref.[7] is suggested that the prior hazard rate ρ be built as:

$$\rho(t) = \xi_0 k_0(t) + \sum_{j=1}^{\infty} \xi_j k(t - \sigma_j), \qquad t \ge 0 \tag{4}$$

where $\xi_0, \xi_1, \xi_2, \dots\dots\dots$ are positive independent random variables, with $\xi_1, \xi_2, \xi_3, \dots\dots$ identically distributed, $\sigma_0 = 0$ and $\sigma_j = \tau_1 + \dots + \tau_j$, $j \geq 1$, with $\tau_1, \tau_2, \tau_3, \dots\dots$ independent of $\xi_0, \xi_1, \xi_2, \dots\dots\dots$ and i.i.d. □ $\varepsilon(q)$, while k_0 is a positive realfunction defined on R+ and integrable on a neighborhood of zero and k is a probability density on R. Note that $\varepsilon(q)$ is the exponential distribution having expected value q^{-1}, where q>0. It will been shown in the following that formula (4) defines, under mild conditions, a valid and possibly smooth hazard rate function.

POSTERIOR DISTRIBUTION

It is here shown that, when the prior hazard rate is defined by Eq. 4, it is straightforward to find an MCMC approximation of the corresponding posterior distribution. Indeed, the interpretation of Eq. 4 in terms of competing hazard sources allows to devise a sort of Gibbs sampler which admits a direct implementation in any programming language. To this aim, let i be the hazard source originating ti, for all i = 1, …, n, so that $t_i = \theta_{i\gamma_i}$; the complete likelihood is then given by:

$$L(\xi,\sigma) = \prod_{i=1}^{n} \left[\xi_{\gamma_i} k_{\gamma_i} (t_i - \sigma_{\gamma_i} \right] \exp\left\{ -\xi_0 K_0(t_i) - \sum_{j=1}^{\infty} \xi_j \left[K(t_i - \sigma_j) - K(-\sigma_j) \right] \right\} \quad (5)$$

where it is worth noting that γ_i plays a role for exact observations.

Considering the prior distribution for (σ, ξ), the following full-conditionals for (γ, σ, ξ) are gamma distributions and thus simulation from them is standard, once it has been noted that K is well known and K_0 can be rewritten as:

$$K_0(t) = q \left\{ \begin{matrix} t\left[1 - K(t)\right] + (2\pi)^{-\frac{1}{2}} \upsilon^{\frac{1}{2}} \\ \left[1 - \exp(-t^2/2\upsilon\right] \end{matrix} \right\}, \quad t \geq 0 \quad (6)$$

Applying R Functions for Bayesian Hazard Rate Estimation, the above formulations are calculated.

RISK MANAGEMENT LEVEL

It has been noted in earthquake events that major disasters need interventions at level with proper coordination, communication and mutual cooperation. Immediately after the earthquake, here exists a chaotic situation with all different organizations. To reach to the victim, it is essential that a centralized coordination, information dissemination and decision making system is in action. At this level, the government agencies play a vital role and should be in the center of this coordination. Equally important are the needs and priorities at the local level and to make the initiative a people owned one.

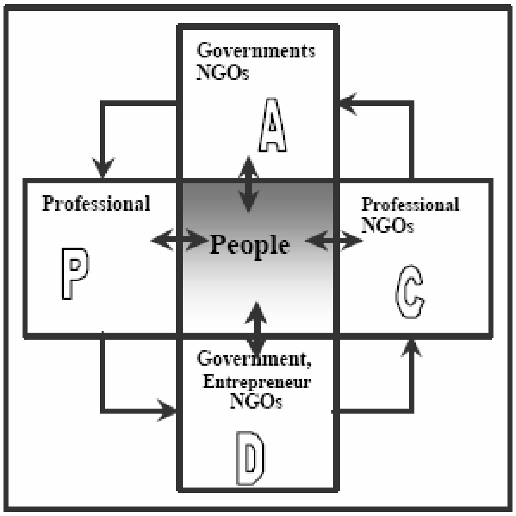

Fig. 1: Risk Management Framework

A level system under the Risk Management Framework is used, which aims to bind the local communities to the decision makers and the international communities. the RM Framework can be correlated to the Plan (P), Do (D), Check (C) and Action (A) of the PDCA cycle. This is exemplified in Fig. 1. Plan combines Identify, Analyze and Evaluate Risk, while Do stands for Treat Risk, Check stands for Monitor and Review and Action for Establishing the Context. In contrast to the standardized practices of the developed nations, implementation of this type of RM Framework is hardly observed in reality in the developing countries. This is not due to lack of resources, but rather due to lack of systems.

Each element of this framework is regarded to be useful tool and is practiced separately, without a systematic and cyclic process. Therefore, a basic system is proposed, which can be implemented in the field; can be considered for policy making and can incorporate different stakeholders in the process.

NUMERICAL STUDY

In the application of Earthquake Risk Management Strategy Plan, a historical records have extended from year 2006 to 1951. Deterministic analysis is selected for this study and nearly 2000 historical seismic records of the earthquakes is used. All earthquake sources which are capable of producing significant ground motion at the site have selected. The distance between the source zones and the studied area were measured and the strongest level of shaking which influence the interested site is selected. Level of shaking is assumed to characterise by the Peak horizontal Ground Acceleration (PGA). Appropriate attenuation relationships are used and effective PGA value is calculated for the interested area. Iran's Fault Zone that is defined as a line type source is selected as a major source for the studied area.

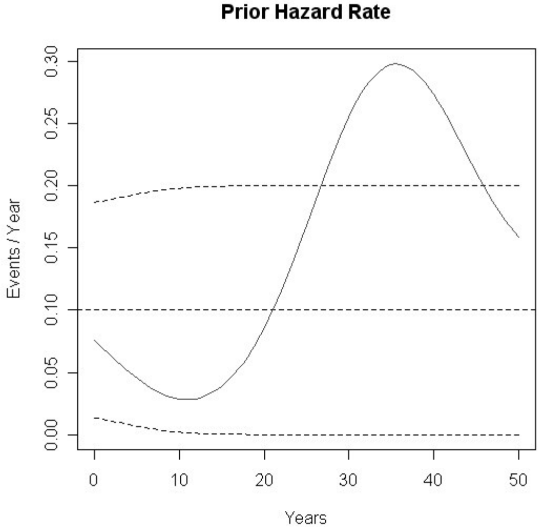
Prior Hazard Rate

Fig. 2: Observed sample path of the Earthquake events with Mw>6.4 in the zone of IRAN from 1951 to 2006

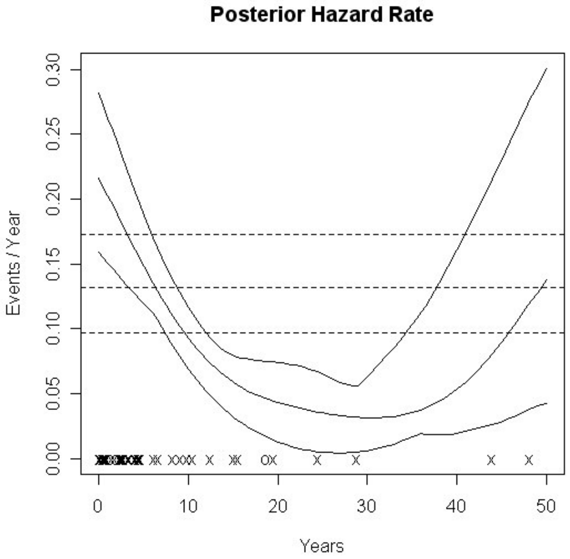
Posterior Hazard Rate

Fig 3: Posterior hazard rate for the inter-event times in the zone of IRAN. The 50 exact observations are marked with X

Table 1: Inventory data of some critical facilities for earthquake risk management in the zone of Iran

Facilities	No. of Facility	Area (m^2)	Length (m)
School	15	17000	
Hospital	10	50000	
Factory	10	100000	
Gas station and Line	5	-	10000
Government Building	70	20000	

The magnitude of the major source that would be effect the area in the future is determined. The earthquake magnitude more than 6.4 is selected according to Richter scale and 0.319 g as a PGA, ground motion parameter for this analysis. The observed sample path of the process counting them such as prior hazard rate is reported in Fig. 2.

According to Fig. 3, the estimated hazard rate for the nonparametric renewal model is bath-tub shaped: there is an increase in seismic hazard immediately after an event occurs, then the hazard goes down to a sort of quiescence level and eventually it goes up again, possibly due to stress accumulation. Note that the after-event increase has nothing to do with aftershocks, as neither these nor foreshocks are recorded in the zone of Iran.

After hazard rate in the zone was estimated, then for vulnerability investigation, a significant effort goes into building inventory data. Generally, inventory data are structured into two classes. Occupancy class data provides information on the use and function of the building environment. The second class provides engineering construction types of similar damage potential for each construction (e.g., concrete, masonry). In this study, occupancy type classification is used for vulnerability investigation. But only hospitals, schools, factories, gas stations and line and governmental buildings were selected as critical facilities. The areas and lengths of critical facilities for earthquake risk management studies were measured (as illustrated by Table 1). It was concluded that, 10 hospital buildings, 15 schools, 10 factories and 70 governmental buildings were under the danger of earthquake hazard. The total area of governmental buildings, which would be effected by the earthquake, is around 20000 (m^2). More than 10000 (m) length main natural gas line exists into this risky area.

CONCLSION

It is concluded that, many critical utilities, lifelines are under the influence of earthquake hazard in the liquefiable zone of the studied area. Approximately hospitals have 50e3 (m^2), schools have 17e3 (m^2) and governmental buildings have 2e03 (m^2) areal coverage in the the danger of earthquake hazard. These facilities must be taken into consideration as soon as possible due to earthquake hazards. More detailed earthquake risk management studies must be put into action in this region. These kind of studies can provide city planners and emergency risk managers key information on potential damages and losses to buildings, critical utilities and transportation systems. City planners, risk managers can use these outcomes and make their strategic plans according to these results. Development in softwares like GIS will increase the developments in loss estimation tools. This developments will influence the race of earthquake risk mitigation in the highly populated urban areas.

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