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Role of Probabilistic Seismic Hazard Analysis in Engineering Design

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ABSTRACT:
Occurrence of few damaging earthquakes during the last decade has pointed to our shortcoming in seismic hazard analysis methods. The main aim of any seismic hazard assessment is to, in some way; quantify the level of ground shaking which can be expected in a given region within a given time. This is naturally dependent on the seismic activity in the region, but also on factors such as the time elapsed since the previous large earthquake, and also the distance to large faults. Approaches to seismic hazard assessment can be grouped into two broad categories: deterministic and probabilistic. Both probabilistic and deterministic methods have a role in seismic hazard and risk analysis performed for decision-making purposes. These two methods can complement one another to provide additional insights to the seismic hazard or risk problem. The probabilistic seismic hazard analysis method is discussed in this paper.

Keywords: Seismic data, earthquakes, hazards, deterministic, probabilistic, ground motion.

INTRODUCTION:

The occurrence of great earthquakes and their effects in India over the last few years warn us of the need to assess the hazard due to earthquakes and prepare for future calamities. The occurrence of seven major damaging earthquakes during the past few decades (1988–2004) is testimony of that. Among the seven earthquakes, three of them occurred in the Peninsular India (1993 Latur Earthquake; 1997 Jabalpur Earthquake; and 2001 Bhuj Earthquake), the other three in the Himalayan region (1988 Bihar-Nepal Earthquake; 1991 Uttarkashi Earthquake; and 1999 Chamoli Earthquake), and the other is the most recent 2004 Sumatra Earthquake, which triggered the tsunami and greatly affected the Andaman and Nicobar Islands. The damage pattern due to earthquakes depends upon the earthquake source type, local site condition, and social developments of the region with the most important condition being the intensity of shaking of ground at the time of the earthquakes. The Peninsular India is generally considered to be stable and less prone to the seismic hazard but the recent past earthquakes of the 1993 Latur, 1997 Jabalpur, and 2001 Bhuj earthquakes and the aftermath indicates even the stable Peninsular India is not safe from earthquake activity.

In the wake of the disastrous events of 26 December 2004 Sumatra (Mw = 9.3) earthquake followed by the earthquake of 8 October 2005 (Mw = 7.6) in Pakistan, there is a need for the mitigation in zones of high risk to seismic hazard. Among all the natural hazards, earthquakes lead the list of natural disasters in terms of damage and human loss, and they affect very large areas, causing death and destruction on a massive scale. Successful earthquake prediction is not feasible and has proved futile in the past.

The Bureau of Indian Standard (BIS) classier India into four seismic zones (zone II to zone V), (Fig.1). However, these zones are not sufficient to predict the damage pattern within each zone in the event of an earthquake, as the damage will depend on the local geology, vicinity to active faults, geotechnical and geophysical properties of surface and subsurface strata, slope instabilities, and topography. Contrasting seismic response is observed even within a short distance over small changes in the geology of the site. Hence, seismic microzonation over a region is needed to minimize the loss to human life and property.

Seismic hazard assessment has an important societal impact in describing levels of ground motions to be expected in a given region in the future. Challenges in seismic hazard assessment are closely associated with the fact that different regions, due to their differences in seism tectonics setting (and hence in earthquake occurrence) as well as socioeconomic conditions, require different and innovative approaches. One of the most important aspects in this regard is the seismicity level and the pre-existing knowledge about seism tectonics and fault behavior in the region. The purpose of this study is to characterize the seismic hazard in India by means of the probabilistic seismic hazard method. This study is timely because of the recent development of new ground motion prediction models for this region as well as the discovery of geologic evidence for the recurrence of large, potentially damaging seismic events in this region.

Types of Seismic Hazard Analysis

Approaches to seismic hazard assessment can be grouped into two broad categories: deterministic and probabilistic (Reiter, 1990).

1 Deterministic Approach: Here, all distances from the sites to the potential earthquake sources, as well as the magnitudes of the earthquakes within the potential sources, are fixed (Reiter, 1990). The result is an estimate of the ground motion that the site would experience given the occurrence of an earthquake at some fixed distance and magnitude. Deterministic seismic hazard analyses are useful for site-specific studies, particularly those involving critical facilities in which the design criteria are based upon the occurrence of the largest possible seismic event (Reiter, 1990). The disadvantage of this type of analysis is that the likelihood of occurrence of the events is not considered and uncertainty in the hazard estimate cannot be analyzed explicitly in a formal, quantitative manner.

2 Probabilistic Approach: A probabilistic seismic hazard analysis provides an estimate of the frequency of exceeding specified levels of ground motion at a site by integrating the contributions of earthquakes of all possible magnitudes and locations in a consistent manner. Introduced by Cornell (1968), this method has many applications in the field of earthquake engineering, including the design or retrofitting of critical facilities (for example, nuclear reactors, bridges, dams, and hospitals) and the containment of hazardous waste. More recently, seismic hazard analyses have also been used for the determination of earthquake insurance coverage of private homes and businesses.

In this approach, distances to potential seismic sources and the magnitudes of earthquakes generated by those sources are treated as random variables (Cornell, 1968; Reiter, 1990). The result is a single hazard curve or set of hazard curves that represent the expected frequency of exceedance of a pre-specified value of motion at a given site. The advantage of this type of seismic hazard analysis is that it models the fundamentally probabilistic nature of seismic hazard. Future earthquakes can occur at a variety of locations and over a range of magnitudes. Because many combinations of magnitude and distance could result in damage to a given structure, a risk-based design approach is desirable for many types of engineering problems. Therefore, the probabilistic approach is the more suitable of the two for most cases. In this study a probabilistic approach is taken because of the need to assess the probability of occurrence of potentially damaging events as well as the uncertainty in the locations of seismically active faults in India.

Methodology of Seismic Hazard Analysis:

The assumption that earthquakes are a random, or stochastic, process is central to the method of probabilistic seismic hazard analysis. If seismic events are statistically independent, then the distribution function of their occurrence times can be represented by the Poisson distribution.

The purpose of this paper is to provide some background information concerning the general methodology followed in conducting probabilistic seismic hazard analyses. The general procedure for a probabilistic seismic hazard analysis requires four steps:

Step 1: The first step involves the identification and delineation of potential sources of seismicity that may affect the site or sites of interest. These sources of seismicity may be represented as area sources, fault sources, or, rarely, point sources, depending upon the geological nature of the sources and available data.
Step 2: In the second step the temporal behavior of earthquakes is determined for each source by establishing a magnitude recurrence relationship over the range of magnitudes that are likely to be generated by each seismic source. Traditionally recurrence models have assumed a Gutenberg- Richter relationship (Log N = a - bM) where N is the number of earthquakes with magnitudes greater than M. However, other recurrence models, such as the characteristic earthquake model are certainly possible and can be applied if appropriate.

Step 3: The third step involves the use of a ground motion prediction model to establish the conditional probability of exceedance of a pre-specified ground motion value for each site given the occurrence of an earthquake at a particular magnitude and location. Ground motion prediction models are derived from strong motion data; the resulting prediction equations usually consist of separate relations for elastic response spectral amplitudes for both hard rock and soft soil sites.

Step 4: The fourth step of the analysis involves the integration of the first three steps over all possible magnitudes and earthquake locations to produce the result of a seismic hazard analysis: A function representing the probability of exceeding various levels of peak ground motion at a specific site.

Also, the term probability can be explained using classical probability concept, according to which one can say that if there are n equally likely possibilities, of which one must occur and s are regarded as favorable, or as “success”, then the probability of a “success” is given by s/n.

For approximating the dispersion of observed data the probability density functions (PDFs) are used, which are integrated to obtain probabilities. In applied probability the most widely used PDFs are based on normal or Gaussian distribution. The analytical form of such PDF of a random variable Z, that is, $f_z(z)$ is given as

$$f_z(z) = \frac{1}{\sqrt{2\pi}\sigma_z} \exp\left[-\frac{1}{2} \left(\frac{z-\mu_z}{\sigma_z} \right)^2 \right] \quad (1)$$

where

$$\mu_z = \int_{-\infty}^{+\infty} z f_z(z) dz \quad (2)$$

and

$$\sigma_z^2 = \int_{-\infty}^{+\infty} (z-\mu_z)^2 f_z(z) dz \quad (3)$$

The constant $1/\sqrt{2\pi}$ in Eq. 1 is selected so that the normalized frequency diagram encloses a unit area; that is,

$$F_z(z) = \int_{-\infty}^{+\infty} f_z(z)dz = 1 \quad (4)$$

which means that the occurrence of Z within its entire range is a certainty.

In the previous equations μ_z is referred to as the mean and σ_z is the standard deviation of the probability densities. A typical PDF of Z with normal distribution is shown in Fig. 3. It should be noted that in applications, the theoretical model is usually selected by setting $\mu_z = \overline{X}$, and $\sigma_z = S$.

For a probabilistic appraisal of the structural safety of a member or a structure, on must have a statistically determined resistance PDF $f_R(r)$, and a corresponding load effect PDF. Again statistical studies show that since the loads are susceptible to variations, their effect on a member or a structure can be expressed in probabilistic form. Such load effects, resembling $f_R(r)$, will be designated as $f_Q(q)$.Two such functions probabilistically defining the load effect $f_Q(q)$ and the resistance $f_R(r)$ for force acting on a member are shown in Fig. 2.

In conventional (deterministic) design, the load magnitudes are usually set above the observed mean. This condition is represented by Q_n in Fig. 2. On the other hand, in order to avoid possible rejections, a supplier will typically provide a material with an average strength slightly greater than specified. For this reason, calculated nominal member resistance R_n would be below the mean. On this basis, the conventional factor of safety is simply defined as R_n / Q_n.

Deterministic and probabilistic seismic hazard analyses should be complementary. The strength of one over the other depends on the earthquake mitigation decisions to be made, on the seismic environment, and on the scope of the project. In general, more complex decisions and subtler, detailed seismic environments strongly suggest the probabilistic analysis, whereas simpler decisions and well-understood seismicity and tectonics point toward deterministic representations. This is not to say that one analysis should be used to the exclusion of the other. In fact the most insight will come from using both, allowing the probabilistic analysis to guide the choice of deterministic events, and letting the deterministic events guide the refinement of the probabilistic analysis. In this way we will make more informed decisions to reduce seismic risk.

Both probabilistic and deterministic methods have a role in seismic hazard and risk analyses performed for decision-making purposes. These two methods can complement one another to provide additional insights to the seismic hazard or risk problem. One method will have priority over the other; depending on how quantitative are the decisions to be made, depending on the seismic environment, and depending on the scope of the project (single site or a region). In many applications a recursive analysis, where deterministic interpretations are triggered by probabilistic results and vice versa, will give the greatest insight and allow the most informed decisions to be made.

CONCLUSION:

Deterministic and probabilistic approaches to assessing earthquake hazards and risks have differences, advantages, and disadvantages that often make the use of one advantageous over the other. Probabilistic methods can be viewed as inclusive of all deterministic events with a finite probability of occurrence. In this context, proper deterministic methods that focus on a single earthquake ensure that that event is realistic, i.e.

that it has a finite probability of occurrence. Factors that influence the choice include the decision to be made (i.e. the purpose of the hazard or risk assessment), the seismic environment (whether the location is in a high, moderate, or low seismic risk region), and the scope of the assessment (whether one is assessing a site risk, a multi-site risk, or risk to a region).It is always important to identify the soil and site for earthquake resistant projects. The adequate and meaningful data must be assessed before seismic analysis and going for earthquake resistant design. So, with continued statistical analysis of collected data, perhaps one day there will be a warning system that will be able to give enough advance notice, so that casualties might be minimized even further.

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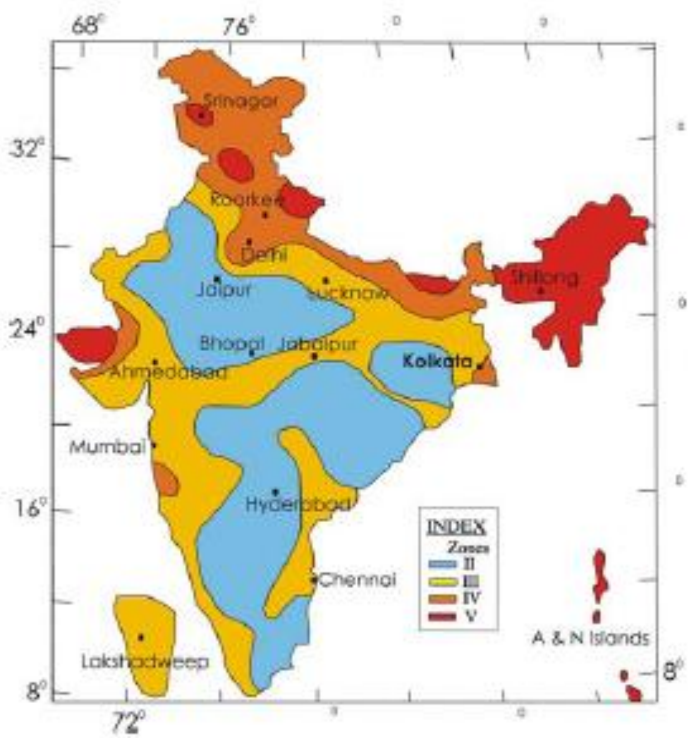

Fig. 1 Map showing the four seismic zones of India.

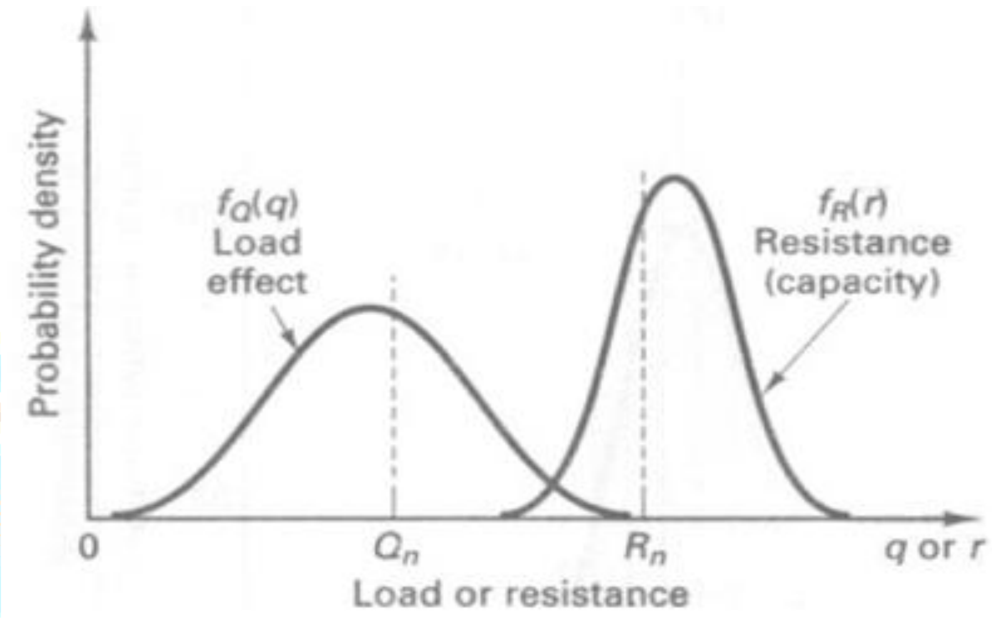

Fig. 2 Probability Density Functions for the two main random variables (load and resistance).

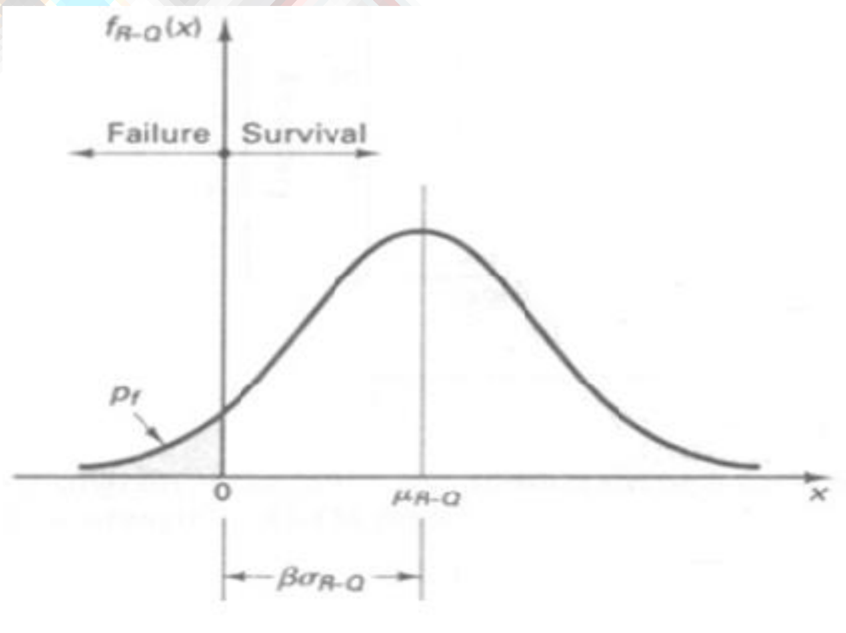

Fig. 3 Normal probability Density Function