

Consideration of the rupture model uncertainties in the probabilistic seismic hazard analysis



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ABSTRACT

The uncertainties associated with the fault rupture model, i.e. down dip rupture width, subsurface rupture length and fault's dip angle are not considered in the conventional probabilistic seismic hazard analyses (PSHA). The dip angle as an epistemic uncertainty is commonly assumed as a fixed value for a specific fault. Additionally, down dip rupture width and subsurface rupture length are determined from empirical relations.

The main hypothesis of this paper was that the results of PSHA may be significantly influenced by considering the rupture model parameters as random variables instead of fixed values. The Monte Carlo simulation, as a powerful tool for uncertainty propagation analysis, was used for this objective. The NGA-West 2 database, as well as the Wells and Coppersmith (1994) [4] study was applied to describe the rupture model parameters in a stochastic manner. The results confirmed that hazard values derived from the Monte Carlo simulation method are significantly different from those derived from the classical approach. Depending on the attenuation relation and the style of faulting, these differences leads to over/underestimation of hazard, especially at shorter periods in a characteristic band of region.

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1. Introduction

The treatment of uncertainties is a key aspect of any probabilistic seismic hazard analysis (PSHA). Distinction is made between two types of uncertainty in seismic hazard assessment. The first type of uncertainties are characterized as epistemic, if the modeler sees a possibility to reduce them by gathering more data or by refining models [1]. The epistemic uncertainties are due to lack of fundamental knowledge, where the very existence of the phenomenon itself is unknown [2]. This type of uncertainty reflects incomplete knowledge of the nature of seismic motion, earthquake generation and rupture characteristics. The second type of uncertainties entitled the aleatory variability represents an apparent randomness in nature of earthquakes, i.e., the scatter associated with the ground motion prediction equations (GMPE). It is obvious that the modeler does not foresee the possibility of reducing the aleatory uncertainties [3].

Based on the abovementioned points, the down dip rupture width (W) and rupture length (L) may be classified as aleatory variability. These aleatory uncertainties have been studied by Wells and Coppersmith (1994) (WC94) [4]. In addition, the fault's

dip angle (δ) is an epistemic uncertainty, since increased knowledge of the fault geometry could reduce its uncertainty [5]. However, the uncertainty associated with the dip can also be treated as aleatory variability for computational purposes [5–7]. For this aim, its distribution can be determined from the existing databases, such as the NGA-West2 database [8].

As a reasonable deduction, the three mentioned parameters can be involved in the probabilistic seismic hazard integration in addition to the other aleatory parameters. Referring to the well-known PSHA integration however, doesn't confirm this expectation. As it is shown in Eq. (1), the earthquake size, location and the ground motion intensity are the only integrated variables in the conventional PSHA to calculate the mean annual rate of exceeding a specific shaking level, x :

$$\lambda(X \geq x) = \sum_{i=1}^{n_{\text{sources}}} v_i \iint f_i(m, r) P(X \geq x | r, m) dr dm \quad (1)$$

where v_i is the mean annual rate of the i th source, m is TE earthquake magnitude, r is the distance to the site, $f_i(\cdot)$ represents the joint probability density function for magnitude and distance. The term $P(\cdot)$ comes from an applied GMPE and stands for the probability of the argument [9]. Eq. (1) confirms that the uncertainty related to the rupture model is ignored in the conventional PSHA.

As a noteworthy comment, the modern GMPEs are considerably more complicated than previous GMPEs and they require

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several extra input parameters other than magnitude, and distance. The NGA models (e.g., Abrahamson and Silva [10], Campbell and Bozorgnia [11] and Chiou and Youngs [12]), for example, apply some of the rupture model parameters in their functional forms due to better understanding of the source of the aleatory variability. Despite the complexity of NGA models, only two major parameters magnitude, and distance are included as stochastic variables in the conventional PSHA (Eq. (1)) and the others are assumed as determined parameters [13]. For instance, the parameters W and L are determined within the empirical relationships as a function of magnitude, and a fixed amount is assumed for δ .

The main objective of this paper is to assess the influence of handling uncertainties associated with rupture model on the final result of seismic hazard studies. For this purpose, Eq. (2) can be proposed to capture these uncertainties in the classical approach:

$$\lambda(X \geq x) = \sum_{i=1}^{n_{\text{sources}}} v_i \iiint f_i(m, r, \delta, W, L, D) P(X \geq x | r, m, \delta, W, L, D) dr dm d\delta dL dW dD \quad (2)$$

Refining the double integral of the classical approach and changing it to Eq. (2) will amplify the computational efforts. To deal with this problem, the integration procedure may be replaced with the Monte Carlo simulation method for hazard assessment. The Monte Carlo simulation approach has been used in many seismic hazard studies in different regions as an alternative method (for further information see e.g., [13–19]). More details on this method will be given in the following sections.

2. Motivation

Before presenting the motivations of the paper, the rupture model parameters are illustrated in Fig. 1. According to the shown rupture surface, dip angle (δ) is the angle from the horizontal, strike (θ) indicates the azimuth of the fault from north where it intersects a horizontal surface, rake angle (λ) point to the angle between the slip vector and the strike, W specifies the down dip rupture width and L is the subsurface rupture length.

Table 1 provides the measured seismic information including, moment magnitude (M_w), δ , W and L for the 1978 Tabas, Iran, earthquake according to Hartzell and Mendoza [21] specific study. Table 1 also includes the expected values of these parameters based on the generic studies for the same moment magnitude and the style of faulting. The generic model for Tabas earthquake in this paper is based on Wells and Coppersmith (WC94) [4] and

Table 1

Tabas seismic information. Amount of W , L and δ for Tabas earthquake and their expected value from generic model based on the WC94 and K11.

$M_w=7.35$, reverse faulting			
Assumption	W (km)	L (km)	δ (deg)
Specific rupture model [21]	35	90	25
Generic rupture model based on the WC94 and K11	25	67	40

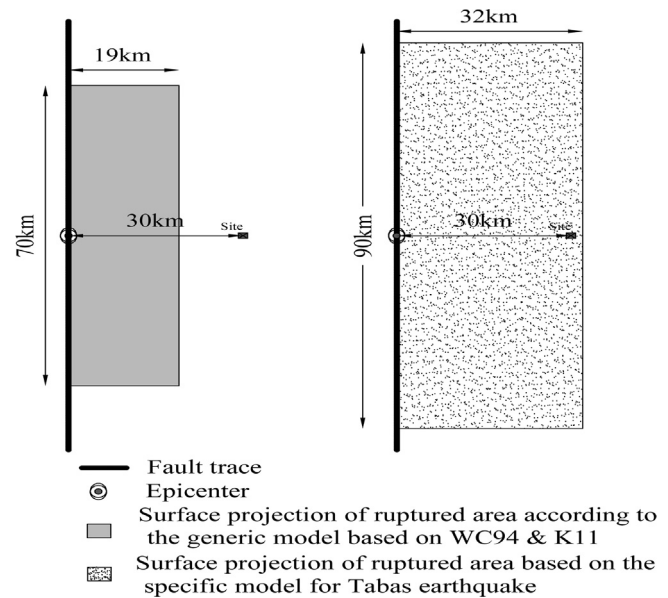


Fig. 2. Layout of an example site dominated by two rupture model assumptions.

Kaklamanos et al. (K11) [20]. The parameters W , and L are calculated using WC94, and K11 is engaged to estimate δ .

Here, a single site located 30 km far from a hypothetical reverse fault with 100 km length and 40 km width is assumed. This single fault which produces earthquakes with only $M_w=7.35$ is shown in Fig. 2. Suppose that earthquakes with this magnitude occur at a rate of $\nu=0.01$ times per year. If the mentioned earthquakes will rupture the fault according to the rupture model proposed by the generic model based on the WC94 and K11 (Table 1), the shortest distance from the site to the surface projection of the ruptured area (R_{JB}) is approximately 11 km in the case of illustrated site. However, when the assumption of the Tabas earthquake with the same magnitude and style of faulting for rupture model was applied, the site was exactly on the surface projection of the ruptured area ($R_{JB}=0$). Accordingly, this considerable difference of source to site distances caused by different assumptions regarding the rupture model can remarkably affect the results of PSHA results.

Furthermore, for employing PSHA, it is assumed that the site has shear wave velocity $V_{s30}=760$ m/s, corresponding to NEHRP Site Class B/C. Moreover, in this paper, five NGA-West 1 GMPEs with equal prior weights to evaluate the uniform hazard spectrum (UHS) for two probabilities of exceedance in 50 years for both assumptions shown in Table 1 are used. The applicability of NGA GMPEs for the Iranian plateau has been proved in many studies such as Ghasemi et al. and Shoja-Taheri et al. [22,23]. Additionally, it has illustrated by Kaklamanos and Baise in 2011 that the NGA models have significantly higher prediction accuracies than their predecessors [24]. Moreover, some of these models include rupture model parameters in their functional forms whereas regional attenuations are very simple that may not include mentioned

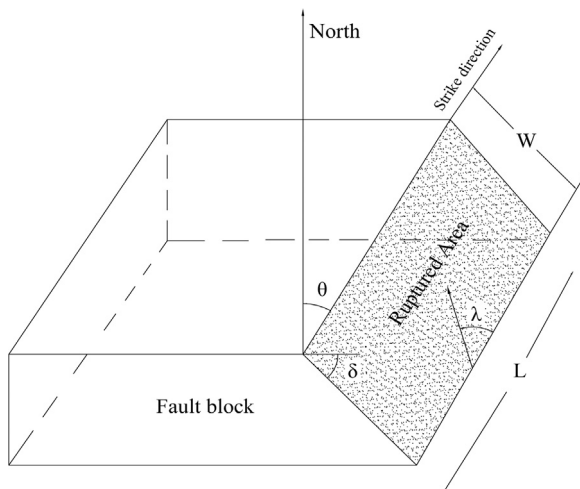


Fig. 1. Illustration of the rupture model parameters.

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