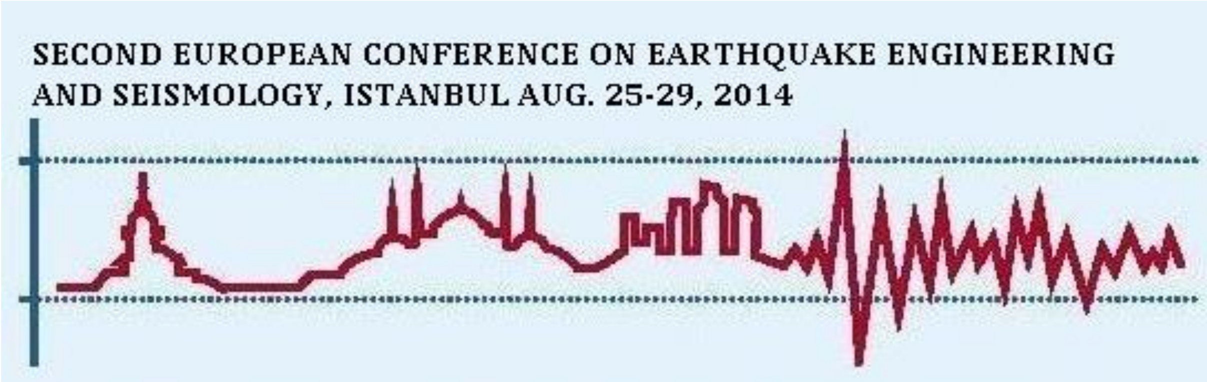

Probabilistic Seismic Hazard Assessment Using Uncertainty Implementation in Synthetically Simulated Strong Ground Motion Records

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ABSTRACT

Probabilistic seismic hazard assessment methodology incorporate uncertainties from earthquake location, recurrence rate and strong ground motion attenuation functions. An alternative approaches is proposed in this paper which uses many simulated strong ground motion records out of many earthquake scenarios. Uncertainties associated with shear wave velocity, asperity setting, Kappa, quality factor and Stress drop are modeled in order to simulate many instance of strong ground motion records using a hybrid method. Both stochastic finite fault and empirical Green's function approaches are used for this purpose. Earthquake scenarios are also simulated based on regional seismotectonic setting and characteristics of active fault in the region. Probabilistic distributions are constructed out of the simulated ground motion records in order to assess exceedance probability of various ground motion level. Various agents of ground motion time histories such as PGA, spectral acceleration, Duration and Arias Intensity computational tool under this study. The model as well as seismotectonic characteristics of the Alborz region in used to assess probabilistic seismic hazard for a test point in Tehran. Hazard Curve has been calculated, distribution of Peak Ground Acceleration in Tehran area and Spectral Acceleration for T=0.3(s) will be presented for 475 and 2475 year return periods.

INTRODUCTION

Estimation of strong ground motion Parameters has a key role in analyzing and designing structures. However, in those regions that high seismicity potential and here is no major instrumental earthquake for them, using strong ground motion parameters is a challenging issue for basic studies or seismic design of structures. In order to meet such requirement, mostly empirical methods of seismic hazard analysis would be applicable in form of attenuation relationships. However, attenuation relationships would be applicable for different tectonic regions and using them is not suitable for other areas. In addition, role of such relationships in efficient estimation of directivity effect and different tectonic regimes can lead to presentation of invalid results. On the other hand, relevant information of strong ground motion and evaluation of its values have a vital role in designing and analyzing structures, infrastructural studies, macroeconomics, insurance issues and writing codes. Using theoretical and simulation methods of ground motion can be a suitable alternative for attenuation relationships and empirical methods.

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In theoretical methods of strong ground motion prediction, through considering relevant information of earthquake source, wave propagation between source and site and also strong ground motion would be simulated. Another priority of theoretical method to empirical method is that, considering relevant information of the source, site's direction and conditions of ground motion parameter would be estimated more accurately. Effective factors in near fault would be also able to be modeled in empirical methods (Erdik and Durukal, 2003). The most important simulation methods can be stochastic finite fault and empirical green function.

Stochastic finite fault method is improved form of Boore stochastic method by and Atkinson (Boore, 2003). At this method, fault plane would be divided to several sub-faults and a Fourier amplitude spectrum has been calculated in equation 1 for each subfault. Afterwards, white gaussian noise would be also multiplied in shape function like Saragoni-Hart Following, Fourier transform would be imposed on white noise and would be then multiplied in spectrum of each subfault. Then, obtained results from every subfault would be transferred to time domain and would be added to time unit through taking time lag into account (Motazedian and Atkinson, 2005).

$$Aij(f) = C\ Moij\ Hij \frac{(2\pi f)^2}{1+(\frac{f}{fctij})^2} \frac{e^{\frac{-\pi f Rij}{Q(f)\beta}}}{Rij} D(f) e^{-\pi f k0} \tag{1}$$

where M_{oij}, f_{ctij} and R_{ij} are the ij subfault seismic moment, dynamic corner frequency and distance from the observation point respectively. The constant C is a radiation pattern, β is the shear wave velocity. The dynamic corner frequency is defined in terms of the shear wave velocity, the seismic moment, the stress parameter and cumulative number of ruptured subfaults. Boore (2009) also made some modifications on the code of finite fault modeling (EXSIM) so it can have better agreement in producing motions with point source modeling (SMSIM, Boore 2005).

The idea of predicting strong motion through using recorded small events, as the empirical green's function, has been presented for the first time in 1978 by Hartzell. In the empirical green's function method, time history of small events would be applied in order to achieve time history of target events. Such small events would be appeared through rupture resulted from a large earthquake . In order to make the method more valid and accurate, all small events should include focal mechanisms similar to target events. The method is based on corner frequency of small events applied in simulation. It is also based on availability of information about small earthquakes. According to proposed model by Irikura (1986), for the purpose of simulation through empirical green function method, fault would be considered as a rectangular plane. Then, using common rules among earthquakes, the mentioned plane would be divided to N×N number of subfaults (Irikura, 1986). Through considering such subfaults as the point source, empirical green functions would be specified for them. Finally, time history of target event would be obtained using equation 2.

$$U(t) = \sum_{i=1}^{N}\sum_{j=1}^{N} \frac{r}{rij} F(t) * (C \cdot u(t)) \tag{2}$$

Where F(t) is filter function, U(t) and u(t) are the time history of target and small events respectively and C is ratio of static and dynamic stress drop.

METHODOLOGY

The main challenging issue in regard with using empirical green's function method is selecting sample small event. The event should include information about path, source and site. On the other hand, selecting suitable small event is an issue that would be occurred rarely. In order to solve such problem, Irikura et al (2000) have proposed hybrid method for simulation. Process of proposed hybrid simulation is depended on selecting suitable small event, having true information about the path and its source; and also providing condition of omega squared by it. After introducing the proposed hybrid method, Irikura et al started to investigate its verification and simulation of earthquake of Hyogo-Ken-Nanbu 1995 with magnitude of 6.9 Consistency of obtained results from the proposed method and observed results indicates efficiency of the proposed method. In proposed method of Irikura et al, low frequencies have been simulated using theoretical green's function method and high frequencies have been also simulated through using stochastically green's function method. Selecting a small event can make results strongly depended on characteristics of same event. Hence, it would be better to select more numbers of small events (Irikura et al,. 2000).

At the present study, first some tools have been produced for purpose of simulating finite fault and selective small events have been produced through Stochastic finite fault method and have entered then to empirical green's function mechanism. Because of lack of enhancement in calculations, both frequency domains have been simulated through the stochastically green's function method. Applied tool has been produced in MATLAB, in which first relevant parameters have been entered to geometry of the fault such as dip, strike, moment magnitude, number of subfaults per length and width, magnitude of selective small event that should be selected considering a desirable ratio of magnitude of target event. Moreover, relevant parameter of direction and site have been also entered to calculations including quality factor, rupture velocity, shear wave velocity, density and other parameters. First, stochastic finite fault simulation has been conducted in order to produce small event and then small event has been selected as the empirical green's function. In order to estimate directivity effect, analytical method of Mavroeidis and Papageorgiou has been applied (Mavroeidis and Papageorgiou, 2003). Moment magnitude is calculated from empirical relationships of Wells and Coppersmith (1994) for each slip mechanism by considering rupture area. In order to validate the program, the TABAS/TAB-LN component during the 1978 Tabas earthquake With magnitude of 7.4 has been simulated and then cumulative arias intensity has been presented in figure 1.

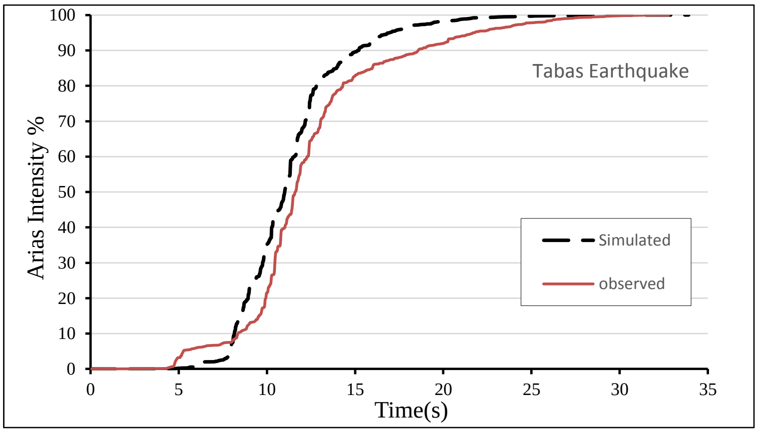

Figure1. Simulated and observed Cumulative Arias Intensity of TABAS/TAB-LN component during the 1978 Tabas earthquake

At the present study, a new study has been conducted following seismic hazard assessment using the mentioned provided tools. Using synthetic acceleration, instead of using attenuation relationship, the rate of exceeding some level of earthquake ground shaking have been measured. The basis of the process is that through iterating simulation for different scenarios of uncertainty of simulation parameters, different results would be obtained for acceleration of a rupture scenario. On the other hand, studies have indicated that amount of produced accelerations for different scenarios of an event have a distribution close to the normal distribution. According to distribution type of every rupture scenario, obtained mean value and standard deviation would be extracted, which are equal to obtained acceleration from its attenuation relationship and standard deviation. Afterwards, in order to evaluate seismic hazard, frequency of seismic sources would be required in order to complete the process. Event frequency in seismic hazard assessment would be obtained by source seismicity and Gutenberg–Richter relation . At the present study, in order to obtain frequency without using the mentioned parameters, SHAP program by Zolfaghari (2009) has been applied (Zolfaghari, 2009). An interesting byproduct about the mentioned software is that seismic and aseismic values of tectonic excitations has been also considered in this database.

$$f\ (a) = \sum_{n=1}^{N} \sum_{m}^{m_u} \lambda_n\ (m_i) \sum_{r_j}^{r_{max}} P_n\ (R = r_j | m_i) \times p(A > a | m_i, r_j) \tag{3}$$

In this method, the occurrence of a ground-motion parameter at a site in exceeding a specified level is a Poisson process if the occurrence of earthquakes is so. Using the Poisson probability model, the probability of exceedance P(a) of a ground motion level a, in design time period t years at a site is related to the annual frequency (or rate) of ground motion exceedance at the site f (a) the annual frequency of exceedance is evaluated by using the equation 3. The values of each Probability for every spectral acceleration or Peak Ground Acceleration in the form of this method will be presented in figure 2.

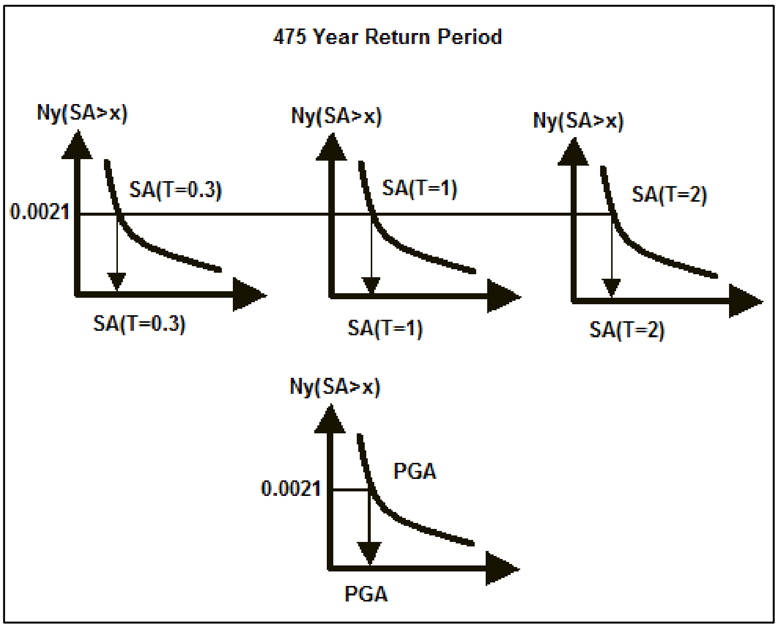

figure 2. Spectral Acceleration and Peak Ground Acceleration for each Probability of occurrence

TEHRAN HAZARD ASSESSMENT AS A CASE STUDY

Tehran region is surrounded by many active faults. these active faults have been caused major earthquakes that have completely destructed the ancient city of Rey in the past (Ambraseys and Melville, 1982). Therefore evaluation of severity of future large earthquake in this city is necessary. Because of significance and high potential of Tehran seismicity, the region has been selected for seismic hazard assessment. Presented parameters in the table 1 have been selected for Tehran Hazard Assessment (Motazedian, 2006). Crustal shear wave velocity and crustal density are taken from the work of Radjaee et al (2010). They determined a model of the crust for the central Alborz Mountains using teleseismic receiver functions from data recorded on a temporarily network. Rupture velocity is considered to be 0.8 times of shear wave velocity. (Beresnev and Atkinson, 1999; Atkinson and Boore, 2006; Motazedian, 2006). Q value, geometric spreading, high cut filter and percentage of pulsing area, are based on the work by Motazedian (2006) for earthquakes in northern Iran.

Table 1. Uncertainty Scenarios for simulation Parameters

	Beta (km/s)	Density(gr/cm^3)	Kappa (s)	Q_0	Q^n
Scenario 1	3	2.4	0.035	50	0.98
Main	3.5	2.8	0.05	87	1.46
Scenario 2	4	3.1	0.065	135	1.91

The following 5 parameters with 3 different values have been considered different simulations that have been conducted for every rupture scenario, so that uncertainty of different parameters of simulation could be considered. On the other hand, according to obtained information from SHAP program, based on rule of equality of moments, every scenario of fault rupture has been divided to several different scenarios. This would lead to consideration of different scenarios of fault rupture and its beginning point. First, assessments have been conducted in site of Civil Faculty of Khaje Nasir University of Technology Which is 51.409 longitude and 35.763 latitude.

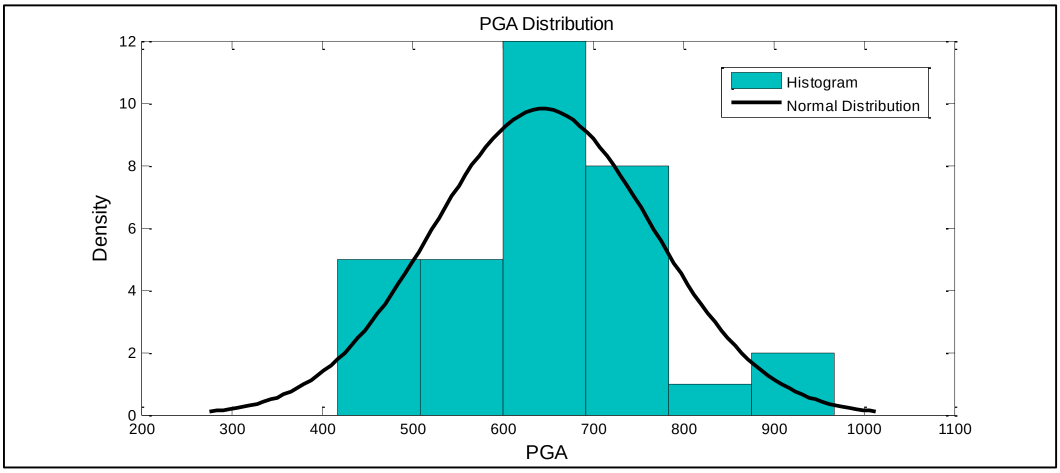

figure 3.Distribution of Maximum Acceleration That affecting site

To recognize the acceleration distribution for each scenario the Histogram of maximum synthetic Accelerations for site will be presented in figure 3. Assessments have been conducted by a 190 kilometers radius of site and 569 ruptures have been reported for the area based on the database. For every scenario of rupture, all of the simulations have been conducted with different parameters. Following, through considering occurrence rate of every event, probable exceedance rate of values has been calculated and Hazard curve has been obtained for the desired site according to figure 4.

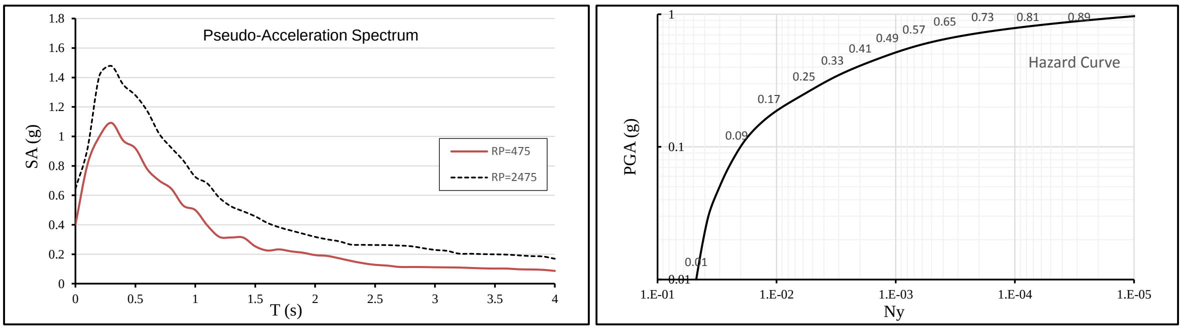

figure 4. Hazard Curve (Right one) and Spectral Acceleration (Left one) for selected site

The same assessments have been also conducted for spectral acceleration and obtained results have been presented in figure 4. It should be mentioned that all results are related to seismic bedrock and amplification effect of upper layer of soil has not been considered. Afterwards, in order to conduct Tehran's hazard assessment, 58 points with equal distance of 5.5km have been selected and then the mentioned hazard assessment process has been conducted for every point. Peak acceleration rates for return periods for Tehran have been obtained to 475 and 2475 years. Obtained results from the assessments have been presented in the presented figures as follows.

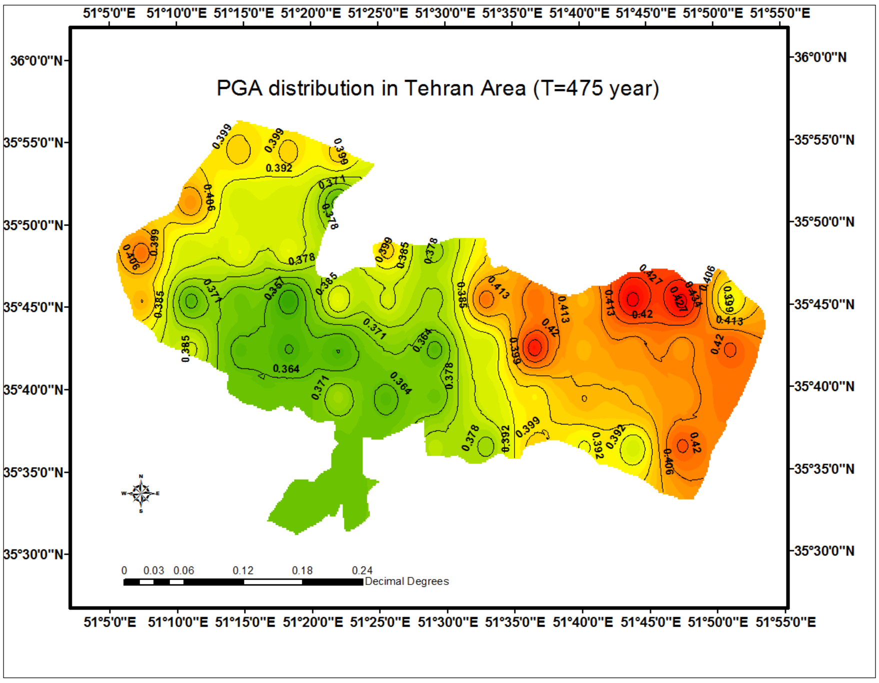

figure 5. PGA distribution in Tehran area for T=475 years

Soil conditions or the effect of top 30(m) of the site profile hasen't been considered here and all the results have been presented for seismic bedrock. By using of some empirical approaches like Boore and Joyner's empirical amplification factors, it is possible to consider the top layer amplification (Boore and Joyner, 1997).

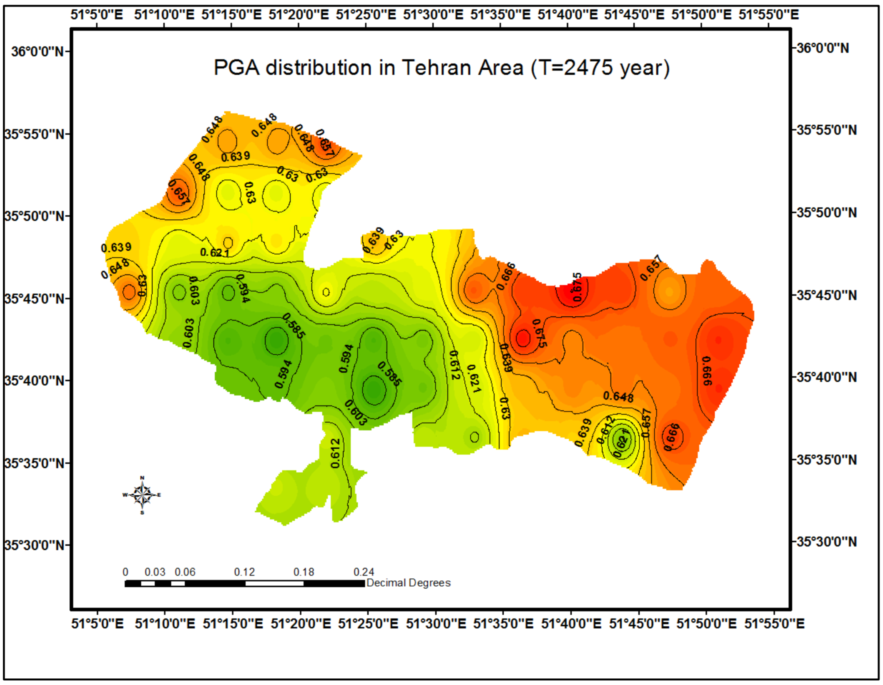

figure 6. PGA distribution in Tehran Area for T=2475 years

Iran's Code of designing sustainable structures has proposed PGA for 475-year return period, using previous studies and seismic hazard assessment and attenuation relations, to 0.35g. Obtained acceleration from the method of the present study has been even to 24% more than proposed PGA in the mentioned Code in some points. Maximum and Minimum values of peak ground acceleration for mentioned return periods has been presented in table 2.

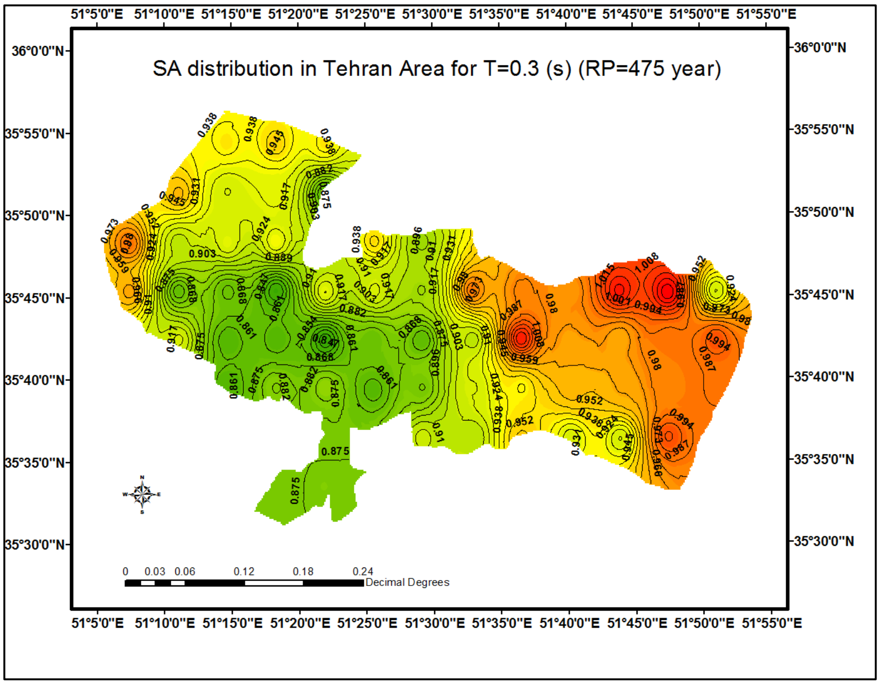

figure 7. Spectral Acceleration (T=0.3 s) distribution in Tehran area for T=475 years

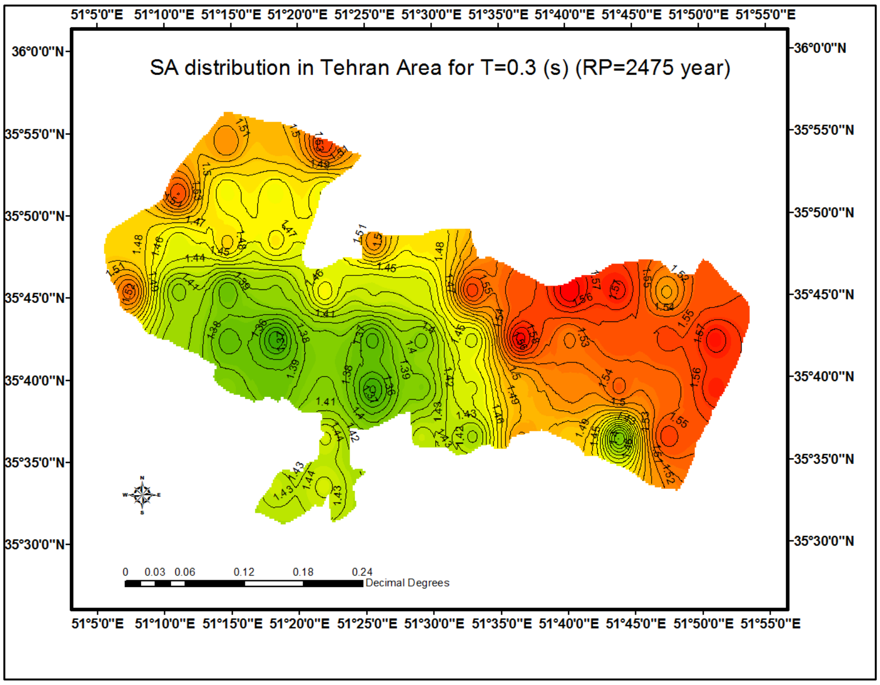

figure 8. Spectral Acceleration (T=0.3 s) distribution in Tehran area for T=2475 years

CONCLUSIONS

Using synthetic acceleration instead of using attenuation relationships for production of motenazer acceleration of every probable earthquake, would not only lead to inaccurate results, but also it may provide an exact and valid estimation. On the other hand, effect of important effective factors on strong ground motion like near field effect can be considered in theoretical methods more efficiently than empirical methods. And also, instead of assessment of a scenario for seismic source, it can be divided to several different scenarios according to rule of equality of moments between small events and target event of the fault. Through this, uncertainty can be typically considered for different scenarios of fault rupture.

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