STRONG GROUND MOTION SIMULATION BASED ON STOCHASTIC FINITE FAULT MODELING FOR TABRIZ, A CITY IN THE NW OF IRAN

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ABSTRACT:

Tabriz, a city in the north west of Iran, has experienced several large destructive historical earthquakes in the past. North Tabriz Fault as an active fault in Tabriz region, with a clear surface expression has caused these large destructive earthquakes in the past. It has an average strike of NW-SE over a length of about 150 km and appears to be generally close to the vertical direction in dip. North Tabriz Fault has been seismically inactive during the last two centuries and due to the absence of ground motion records in Tabriz region, simulation of future events based on regional seismicity information and ground motion model is necessary. In this regard, seismic hazard deaggregation is performed for 10% and 2% probability of exceedance in 50 years and earthquake simulation is done based on the deaggregation results. Attenuation equations developed by Sadigh (1997), Atkinson-Silva (2000) and Campbell-Bozorgnia (2003), have been considered to model epistemic uncertainty having potential errors in the physical description of seismic wave attenuation and equal weights are considered for these attenuation equations. Seismic hazard deaggregation and uniform hazard spectra are computed based on these attenuation equations. The mean magnitudes and distances for PGA and different spectral accelerations are calculated using seismic hazard deaggregation for return periods of 475 and 2475 year. Strong ground motions due to the activation of North Tabriz Fault have been simulated based on stochastic finite fault modeling considering the calculated mean magnitude for return period of 475 year. In order to be taken the stress drop uncertainty in account, stress drops of 20, 40 and 60 bars have been considered in the simulations. Based on these different stress drops, firstly, suites of ground motions have been simulated for return period of 475 year and secondly, their spectral accelerations have been compared with the corresponding uniform hazard spectra. Regarding this comparison, it can be concluded that for the return period of 475 year, a stress drop of about 60 bars generates more compatible spectral accelerations with the corresponding uniform hazard spectra.

KEYWORDS: Seismic Hazard Deaggregation, Earthquake Simulation, Stochastic Finite Fault, Stress Drop, Tabriz city

1. INTRODUCTION

Probabilistic Seismic Hazard Analysis (PSHA) is generally used to display the relative contributions to the hazard from different values of the random components of the problem, specifically magnitude (M), source to site distance (R) and ε, a deviation measure of the ground motion from a predicted (median) value. The process of determining the relative contribution in terms of magnitude and distance is called deaggregation. To make the results of probabilistic seismic hazard assessment more effective, deaggregation procedure can be used for engineering purposes. Ground motion parameters for engineering purposes can be obtained (generated or selected) for these (*M*, *R*) pairs [1].

Simulation of strong ground motion for future events based on regional seismicity information and ground motion model is necessary due to the absence of ground motion records in this area. In this regard seismic hazard deaggregation is applied to estimate magnitude for return period of 475 year. Then, we have applied the stochastic finite fault modeling to simulate the ground motions in Tabriz at selected observation points.

2. TECTONIC AND SEISMICITY OF TABRIZ REGION

Tabriz region is located in the Araxes structural block of northwest of Iran, the southwest continuation of the western Alborz Mountains toward Caucasus. North Tabriz fault as an active one in Tabriz region, with a clear surface expression has experienced several large destructive earthquakes in the past. It has an average strike of NW-SE over a length of about 150 km and appears to be generally close to the vertical direction in dip [2]. Although Tabriz Fault has not generated any large earthquake during the last two centuries, many historical earthquakes have occurred in the Tabriz region (e.g., the 858, 1042, 1304, 1593, 1641, 1717, 1721, 1780 and 1786) [3].
North Tabriz Fault, however, has been seismically inactive during the last two centuries. Therefore, it is important to estimate the ground motion parameters, regarding the future earthquakes which may occur in the north of Tabriz, the most potential seismic source adjacent to Tabriz.

3. METHOD

3.1. Seismic Hazard Deaggregation

For a given site hazard, the annual probability of exceedance (PE) of a specified ground motion or spectral acceleration, u_0, is as follows:

$$\Pr\,[u > u_0] = \sum_M \sum_R \sum_i \text{Rate}(\text{Source}(M,R))\text{Wt}(A_i)\Pr[u > u_0 \,|\, M,R,A_i] \tag{3.1}$$

The first summation is over source magnitude, M from M_{min} to M_{max} which M is moment magnitude, the second summation is over site to source distance, R, and finally the third summation is over the different models of attenuation, each having a preassigned weight, Wt (A_i). The rate factor in Eqn. 3.1. is the mean annual rate of source occurrence (M , R). The conditional probability factor, Pr[•], is the probability of exceedance of the ground motion level, given the source magnitude (M), distance(R) and the models of seismic wave attenuation(A_i). Epistemic uncertainty in the ground motion for a certain source is usually treated using a number of attenuation models. The summation of the annual frequencies in Eqn. 3.1. is generally called an aggregation of the contributions from each elementary source. Deaggregation is exactly opposite to the aggregation in which the contributions are separated versus magnitude and distance.
In this study, attenuation equations developed by Sadigh (1997) [4], Atkinson-Silva (2000) [5] and Campbell-Bozorgnia (2003) [6], have been considered to model epistemic uncertainty having potential errors in the physical description of seismic wave attenuation and associated source size. These relations are selected because the developed attenuation relations in Iran can not predict ground motions at the distances below 30 km due the lack of data. Equal weights are considered for these attenuation relationships. Based on these attenuation relations, probabilistic seismic hazard analysis has been applied.
In our study, the most predominant source is North Tabriz Fault on which several destructive earthquakes occurred on this fault. Based on the paleoseismological studies, we have considered the slip rate for North Tabriz Fault [2]. Therefore, the rate at which earthquake occurred in PSHA analysis is mm/yr instead of conventional activity rate (number of events/yr with M>M_{min}).

3.2. Stochastic Finite Fault Modeling Approach

The stochastic model is widely used to simulate acceleration time histories. The goal of this method is to generate a transient time series having a stochastic character and a spectrum matched to the specified desired amplitude [7]. A window is applied to a time series of Gaussian noise with zero mean and unit variance. The windowed time series is transformed to the frequency domain and the amplitude spectrum of the random time series is multiplied by the desired spectrum. Transformation back to the time domain results in a stochastic time series whose amplitude spectrum is the same as the desired one on average. The application of this method clearly requires the specification of the target amplitude spectrum of the earthquake to be simulated. Therefore, the stochastic method needs a model that specifies the Fourier spectrum of ground motion as a function of magnitude and distance. The acceleration spectrum is usually modeled by a spectrum with an ω^2 shape where ω is angular frequency [7]. In Brune model, spectrum is derived from an instantaneous shear dislocation at a point. The acceleration spectrum of the shear waves A (f), at hypocentral distance R from an earthquake is calculated by:

$$A(f) = (CM_0\,(2\,\pi f)^2 / [1+ (f/f_0)^2])\ \exp(-\pi f R / Q \beta)\ \exp(-\pi f \kappa)\ D(f)/R \qquad (3.2)$$

where M_0 is seismic moment and f_0 is corner frequency, which is given by:

$$f_0 = 4.9*10^6\,\beta\,(\Delta\sigma/M_0)^{1/3} \qquad (3.3)$$

where $\Delta\sigma$ is stress parameter in bars, M_0 is in dyne-cm and β is shear wave velocity in km/s. The constant $C= \Re_{\theta\varphi}\ FV / (4\pi\rho\beta^3)$; where $\Re_{\theta\varphi}$ is the root mean square of radiation coefficients (average value of 0.55 for shear waves), F is free surface amplification (2.0), V is partition into two horizontal components (0.71), ρ is density and R is hypocentral distance [7]. The term exp ($-\pi f\kappa$) is a high cut filter to model zero distance "*kappa*" effects: this is the common observed rapid spectral decay at high frequencies [8]. The quality factor, *Q* (*f*), is inversely related to anelastic attenuation. The term 1/R shows the geometrical spreading, appropriate for body wave spreading in a whole space. 1/R can be changed, once needed, in order to be taken into account the presence of the postcritical reflections from Moho discontinuity. D(f) is the site amplification term, a function of soil type and frequency.

In extending point source modeling to finite fault modeling, a large fault is divided into N subfaults and each subfault is considered as a small point source introduced by Hartzell in 1978 [9]. The rupture spreads radially from the hypocenter. The ground motions of subfaults, each of which is calculated by the stochastic point source method, are summed by a proper delay time in the time domain to obtain the ground motion acceleration. This delay time is related to the distance between each subfault and the observation point. Delay time depends on the location of hypocenter and rupture velocity too. Finite fault modeling emphasizes the effects of fault dimension, rupture propagation, directivity and source receiver geometry.

In this study a program named EXSIM is used for earthquake simulation. EXSIM is a program developed by Motazedian and Atkinson in 2005 for earthquake simulation based on dynamic corner frequency using stochastic finite fault modeling [10].

3.3 Model Parameters

EXSIM requires region specific attenuation and some generic site parameters presented in Table 3.1. Wells and Coopersmith equations were adopted for calculating the fault dimensions for moment magnitude of 6.8 (return period of 475 year) [11]. In this research, California based generic crustal amplification for rock and soil sites proposed by Boore and Joyner (1997) was applied for the stations [12]. Based on present information about the soil type at the stations, simulation is performed for generic rock sites which are equivalent to NEHRP C [13]. A random slip distribution and location for hypocenter is assumed because of having no detailed information about the probable asperities in North Tabriz Fault. In this study, Saragoni-Hart function is used as a window function. In the near source, where there is a subfault size dependency, Bresnev and Atkinson equation (log dl= -2.0+0.4M) is used to calculate the size of subfaults [14]. Here, once EXSIM has been used without considering its analytical option and once the simulations are done using this option of EXSIM.

Table 3.1 Model parameters used in stochastic finite fault simulation

Dip	80
Strike	125
Fault length(M6.8)	44km
Fault width(M6.8)	12km
Fault length(M7.0)	59km
Fault width(M7.0)	14km
Geometrical spreading	r^{-1}
Ground motion duration	$T(R)=T_0+0.1R$ $T_0=1/(2fa)$ Log(fa)=2.41-0.533M
Quality factor	$147f^{0.97}$
Kappa	0.035
Shear wave velocity(β)	3.2km/s
Rupture velocity	0.8β
Density	2.8g/cm^3
Stress parameter(475yr)	20,40,60 bars
Pulsing area percentage	100%

4. EARTHQUAKE SIMULATION

Tabriz is classified as a very high hazard region in the NW of Iran according to GSHAP map [15] and Iranian code of practice for seismic resistant design of buildings [16]. Modeling methods can be used to estimate strong ground motions in a hypothetical earthquake for Tabriz where there is no strong motion data. In this study, seismic hazard deaggregation is applied to estimate the magnitude for simulation of strong ground motions. The mean magnitudes and distances for PGA are calculated 6.8 and 3.9 km for return period of 475 year. The estimated magnitude for return period of 475 year based on seismic hazard deaggregation is used for simulation of strong ground motion due to the activation of North Tabriz Fault.

Strong ground motions have been simulated at T1, T3, T4 and T5 stations in Tabriz. (Fig. 4.1) using the modeling parameters, given in Table 4.1. To simulate strong ground motions generated by North Tabriz Fault, the most dominant source, the method presented by Motazedian and Atkinson (2005) has been used applying EXSIM program [10].

The average shear wave velocities at all stations are in the range of 360m/s-760m/s (NEHRP C class). Wells and Coppersmith equations (1994) have been used for estimation of fault dimensions [11]. The ground motions at a particular point are affected by source, path and site condition. To consider the source effect on the simulated ground motion, the strike and dip of North Tabriz Fault have been used based on the available geological information. The effect of path is considered based on geometrical and anelastic attenuation (Table 3.1). Frequency dependent equation for Q (quality factor) is used as $Q(f) = 147\ f^{0.97}$ [17] and site condition is considered according to the information given by Building and Housing Research Center [13].

In this study, different stress parameters- $\Delta\sigma_1$,. $\Delta\sigma_2$ and $\Delta\sigma_3$ of 20, 40 and 60 bars, respectively, have been considered for return period of 475 year because of having no information on stress parameter in this region. In this research, random location of hypocenter and random case for slip distribution on the causative fault have been studied. The estimated peak ground accelerations are presented in Table 4.1 for stress parameters of 20, 40 and 60 bars for return period of 475 year. Such estimations can be effective in deciding the earthquake resistant design criteria for structures, planned in an area. The simulated spectral accelerations using the above mentioned stress parameters and uniform hazard spectrum for 475 year return period and Iranian code spectrum [16] are compared at all stations (Fig. 4.2). It is observed that Iranian code predicts larger values for periods greater than 1 sec comparing to simulated response spectra for stress parameters of 20, 40 and 60 bars at all four stations for return period of 475 year. Regarding this Figure, it can be concluded that for the return period of 475 year, a stress parameter of about 60 bars generates more compatible spectral accelerations with the corresponding uniform hazard spectrum. Using the stress parameter of 60 bars leads to relatively overestimated results, reliable enough for seismic design or dynamic analysis. It seems that the stochastic finite fault modeling is more capable in simulating high frequencies rather than low frequencies, because the stochastic modeling is fundamentally based on simulation of high frequencies. Moreover, in small distances, near field effects (e.g. directivity) increase the amplitudes of long period pulses.

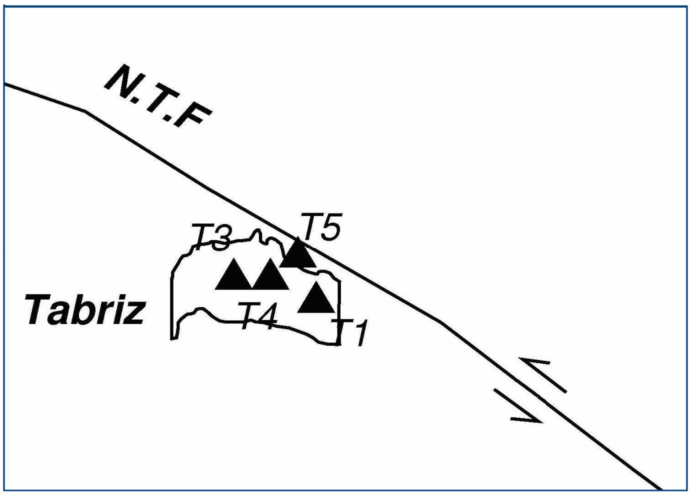
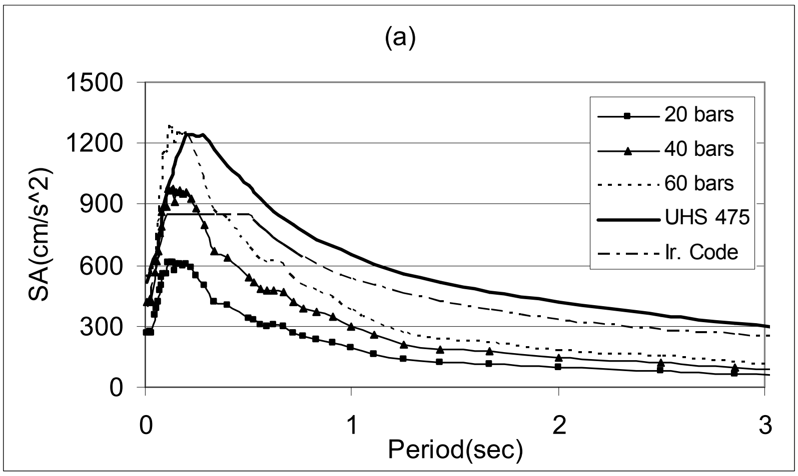
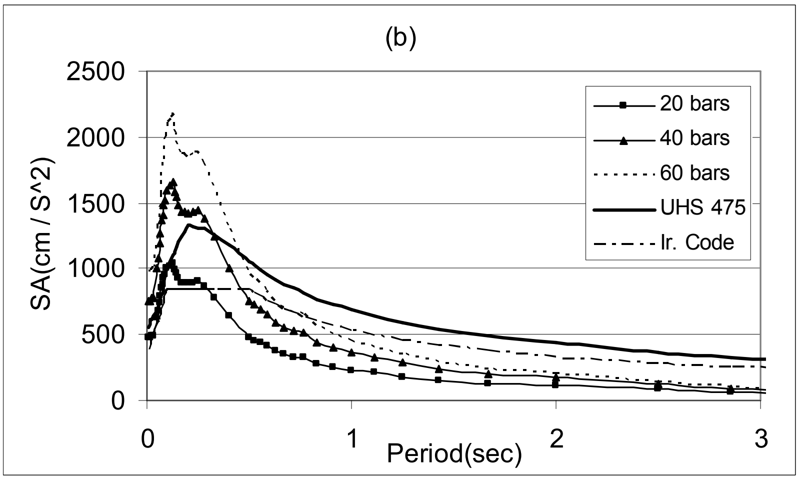


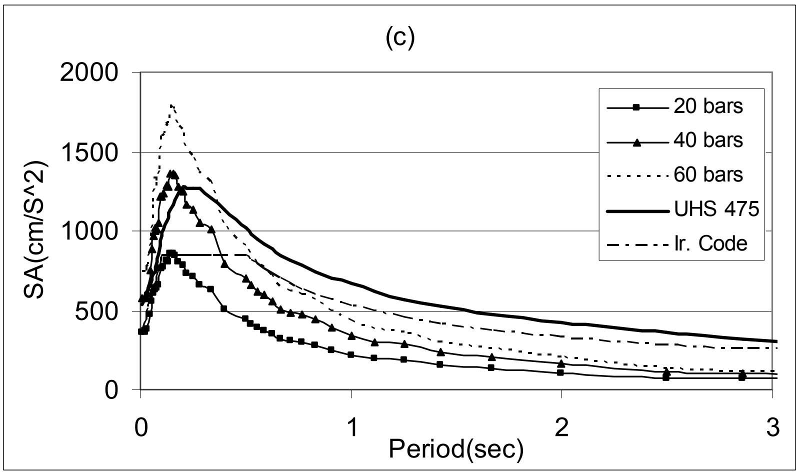
Figure 4.1 Locations of stations and Tabriz around the North Tabriz Fault.

Table 4.1 Simulated PGA using different stress parameters for return period of 475 year

Return Period	Station	Longitude	Latitude	Distance (km)	PGA(cm/s^2)		
					$\Delta\sigma_1$	$\Delta\sigma_2$	$\Delta\sigma_3$
475yr	Tabriz1	46.35E	38.06N	2.36	266	422	553
	Tabriz3	46.26E	38.08N	1.18	475	758	995
	Tabriz4	46.30E	38.08N	1.81	362	575	754
	Tabriz5	46.33E	38.10N	4.90	242	384	503


(a)
1500
1200
900
600
300
0
SA(cm/s^2)
0
1
2
3
Period(sec)
20 bars
40 bars
60 bars
UHS 475
Ir. Code


(b)
2500
2000
1500
1000
500
0
SA(cm / S^2)
0
1
2
3
Period(sec)
20 bars
40 bars
60 bars
UHS 475
Ir. Code


(c)
2000
1500
1000
500
0
SA(cm/S^2)
0
1
2
3
Period(sec)
20 bars
40 bars
60 bars
UHS 475
Ir. Code

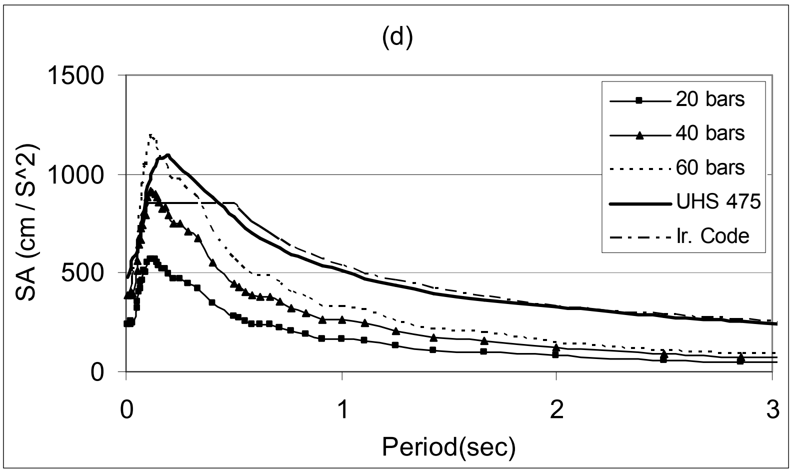


Figure 4.2 Comparison between uniform hazard spectrum and simulated spectral accelerations at a) Tabriz1 b) Tabriz3 c) Tabriz4 and d) Tabriz5 stations for 475 year return period.

5. CONCLUSION

In this research the most potential source for Tabriz is identified upon the seismic hazard deaggregation and the mean magnitudes and distances are estimated for return periods of 475 and 2475 year. For return period of 475 year, seismic hazard deaggregation leads to magnitude of 6.8, used in the earthquake simulation upon stochastic finite fault modeling. Using this modeling, strong ground motions are simulated for return period of 475 year at 4 stations in Tabriz. Comparing the simulated spectral accelerations and their corresponding uniform hazard spectra, it is concluded that more compatible spectral accelerations with the corresponding uniform hazard spectra are generated by a stress parameter of about 60 bars for the return period of 475 year.

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