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PREDICTION OF M_W=7 EARTHQUAKE IN TEHRAN, USING EMPIRICAL GREEN FUNCTIONS

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ABSTRACT

In low seismicity areas such as Tehran, quantitative statements on strong ground motion, suffer from the lack of instrumental strong motion data although the historic catalogue indicates that events of moment magnitudes up to M_w=7 are conceivable in this area. Therefore, the existence of strong historic seismic events leads to the widely accepted conclusion that Tehran is located in very dangerous seismic area. The purpose of this study is to predict acceleration time-history and a range of engineering parameters and pseudo acceleration spectra in the frequency range of 0.3-25 Hz for future near field earthquake in Tehran. The prediction methodology used in this paper, involves developing a set of rupture scenarios derived from bounds on rupture parameters and then calculation of synthetic strong motions for each rupture scenario. The bounds on rupture parameters are limited to what is known about the earthquake, its tectonic and geological environment. Our results encourage the application of this approach as a powerful supplementary tool for site-specific strong ground motion prediction in low-seismicity regions such as Tehran.

Introduction

Evaluation of seismic hazard requires the prediction of strong ground motion from earthquake that poses a potential threat to the population. In recent years, seismologists have attempted to develop quantitative models of earthquake rupture process with the ultimate goal of predicting strong ground motion. Modeling seismograms requires combination of the source, path and site effects, but for frequencies > 1 Hz, this task is very difficult due to limited knowledge of the 3D heterogeneous earth structure. Using records of small earthquakes can overcome the limited resolution of existing structural models.

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We modeled Strong motion seismograms for longitudinal, transverse and vertical components, in the frequency range 0.3 to 25 Hz, and we predicted a range of engineering parameters (Peak Ground Acceleration, Acceleration Root Mean Square, and Duration) and pseudo acceleration spectra for future earthquake in Tehran. In order to obtain a variety of strong ground motion time-histories, we defined 20 rupture scenarios based on previous studies of the Tehran city. We calculated the rupture scenarios using EGF as input record leading to 60 computed time-histories. Finally, in the absence of actual recordings of an M_w=7 earthquake in the defined epicentral region, we compare the peak horizontal and vertical acceleration with attenuation laws computed for world by Campbell and Bozorgnia (2003). Additionally, we compared the calculated response spectra with those suggested by Campbell and Bozorgnia (2003). This attenuation relation is valid for a distance of 60 km in seismogenic rupture zone ($r_{seis} \leq 60$ km) of shallow crustal earthquakes in near-source attenuation similar to California. Most data are from California with some from Alaska, Armenia, Canada, Hawaii, India, Iran, Japan, Mexico, Nicaragua, Turkey and Uzbekistan. Furthermore, we compared the spectral shapes from this study by EGF method with recommended ones by SEAOC for soil type 2 and spectral shapes proposed by Peng et al. (1989) for two different durations.

Methodology

Hartzell (1978) and Wu (1978) published the concept of using EGFs . Several approaches were developed based on the suggested principles (Hutchings & Wu 1990; Irikura 1983; Wennerberg1990 and etc.); these approaches differ primarily in whether they use scaling relations or not and whether timing of the summation is kinematic or incorporates stochastic summation. Two main classes of EGF approaches can roughly be distinguished: the composite and the rupture parameter approach. In order to synthesize strong ground motion seismograms, we use an empirical Green’s function approach that has been successfully applied for site-specific strong ground motion modeling at sites in California (Hutchings 1991, and 1994; Jarpe & Kasameyer 1996). Nevertheless, in this study $4.0<M\leq 5$ events instead of very small events have been used. For this purpose, impulsive point shear source empirical Green’s functions have been generated by deconvolving out the source contribution of moderate-size events.

Data and Site Condition

The March 9, 2003, M_w=4.1 Tehran earthquake occurred about 9 km from the north-Tehran fault at the northeast of Tehran. It was the first recorded moderate earthquake ever to have been reported at a distance less than 20 km from the center of the metropolitan area of Tehran. Digitized three-component recordings from the March 9, 2003, M_w=4.1 Tehran earthquake were obtained by building & house research center (BHRC). All the instruments are of SSA-2 type with threshold of 10 gals. Table 1 lists the recording site location, also site category of stations that have recorded this earthquake. The peak ground accelerations for corrected records ranged from 5 to 50 cm/s^2. Table 2 lists magnitudes, focal depth and epicenter location for this earthquake that have been reported by International Institute Earthquake Engineering and Seismology (IIEES) and Building and Housing Research Center (BHRC). Figure 1 show the locations of recording stations of earthquake used to obtain empirical Green‘s functions.

The existence of strong historic seismic events leads to the widely accepted conclusion that Tehran is a very dangerous area seismically. Figure 2 show the epicenter location and magnitude of historical main shocks and the March 9, 2003, Tehran earthquake. According to the regional tectonic conditions of The Alborz Area on Iranian plateau, the fault mechanisms of earthquakes are compressional, strike-slip or a combination of these two mechanisms (Fig.3). Moreover, mechanism of Tehran earthquake (March 9, 2003) that has been used as EGF in the present study has been showed in figure3 and it is similar to other earthquakes that occurred in this area.

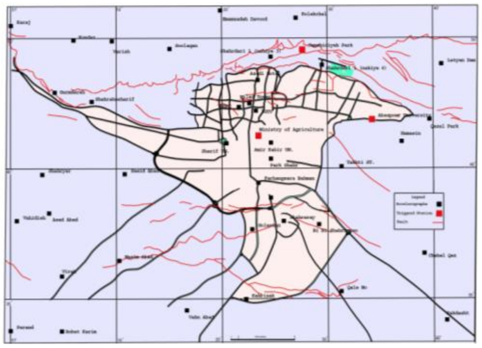

Figure 1. Tehran region and location of stations which are recorded Tehran earthquake (M=4.1).

Records were baseline corrected and filtered with cutoff frequencies determined by visual inspection in order to maximize signal to noise ratio within band. The threshold level of 3 for signal to noise ratio is selected to delimitate the frequency band where the information is meaningful.

Because of ministry of agriculture record has been obtained in 20th floor of building, we do not use this data as EGF for simulating future Tehran earthquake. Abbaspour University record shows high quality reliable data. Therefore, Abbaspour University record is selected to predict strong ground motion using an empirical Green function method at Tehran. The site class of this station is estimated based on the transfer function method. The site amplification of Abbaspour University station based on H/V amplification function occurs in near 12 Hz. Thus, the soil category of this site is class 2.

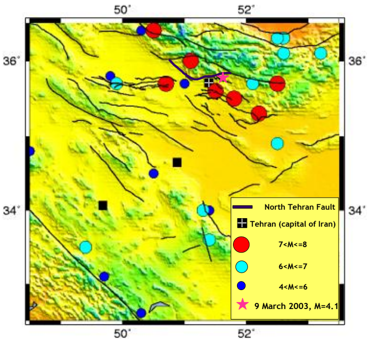

Figure 2. Active faults, North-Tehran fault, epicentre location of historical and the 9 march 2003, M=4.1 Tehran

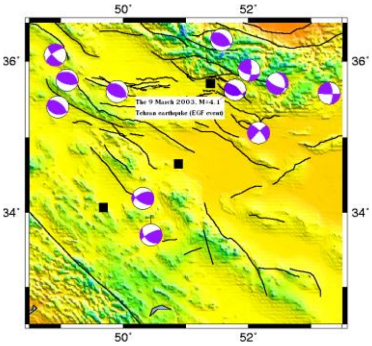

Figure 3. The fault mechanisms of some pervious earthquakes and the 9 March 2003, Tehran earthquake

earthquakes

Table 1: Coordinate of recording station, azimuth of two horizontal components, and soil type

Station	Record No	Geographical Coordinates		Altitude (m)	Azimuth		*Soil Type
		E	N		L	T	
PARK JAMSHIDIYEH	2968	51.46	35.82	0	195	285	Group 1**
ABBASPOUR UNIVERSITY	2970	51.57	35.73	1500	290	20	Group 2
MINISTRY OF AGRICULTURE	2969	51.39	35.71	0	274	4	-

* Soil Type was estimated base on Site Amplification (SAM) where signal to noise ratio is acceptable.

**Group 1: rock and hard alluvial; Group 2: alluvial and thin soft alluvium; Group 3: soft gravel and sandy; Group 4: soft soil and thick soft alluvium

Table 2: Magnitudes, focal depth and epicentre location for the 9 March 2003, Tehran earthquake

No.	Reference	EP Coordinate		ED (km)	m_b	M_s	M_w	Ml
		E	N					
1	IIEES	51.68	35.7	10	-	-	-	4
2	BHRC	51.49	35.74	-	4.1	-	-	-

Predicting a Range of Ground Motions

We chose 20 possible scenarios on the north-Tehran fault, which has the considered capacity of producing earthquakes of Mw=7.0. Tehran March 9, 2003, M_w=4.1 earthquake, can be used as small event for simulating of future strong motion. “The rupture parameter approach” used here, requires small events. The small earthquake may then be considered as having an effective step-impulsive source time function. By deconvolving the assumed source time function and normalizing the time-series of the small earthquake with its moment, records of the these events can be used directly in the representation relation (Aki& Richards 1980) as empirical Green’s function as shown by Hutchings et al. (2003). The actual rupture process is simulated by adding up EGFs using a kinematic rupture model. Therefore, the fault plane of the target event is discretized into elemental areas that are small enough to model continuous rupture up to the highest frequency of interest. Rupture parameters are selected randomly. The limits of input parameters will naturally bound the range of synthesized ground motions (Table 3). In addition, because input parameters are correlated through physical model, unrealistic combinations that cannot happen in nature are excluded. Here, general limits as obtained in the literature were utilized. The velocity structure is considered as 3.2 km/s based on analysis of Rayleigh wave dispersion (Kamalian, 1994). Rupture velocity is considered to be 80% of S-wave velocity i.e., 2.57 km/s. Figure 4 show three components of synthesized accelerograms for different source models (for example, models of 7 and 16).

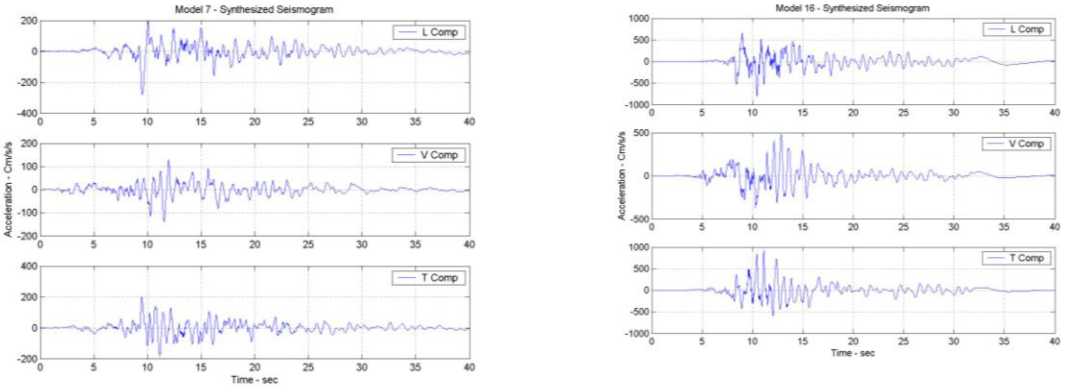

Figure 4. Computed accelerograms at Abbaspour University station in Model 7 and 16

Prediction of Uncertainties

Abrahamson, et al.1990, recognized that the bias and errors arise from three sources: 1- modeling error caused by the approximations and incorrect assumption in the method of calculation; 2- random error caused by the details of the source and propagation that cannot be measured or modeled deterministically; 3- parametric uncertainty caused by uncertainty about the detailed characteristics of a particular future earthquake. They also pointed out that we cannot separate modeling and random uncertainty, so we can only estimate their combined effect, which we do in this section, ignoring parametric uncertainty.

The standard engineering parameters chosen by the authors for evaluating the uncertainty related with the prediction are the Peak Ground Acceleration (PGA), Acceleration Root Mean Square (Acc. RMS), Duration and Pseudo Acceleration Response Spectra (PSA). The hazard is defined by calculating the PGA, Acc RMS, Duration and PSA values of the synthetic ground motion waveforms, calculated as the average of the log of longitudinal and transverse components and also, as the log of vertical component. The estimation of the median (lognormal mean) hazard resulting is:

$$\hat{H}_j = \frac{1}{n}\sum_{i=1}^{n}\log(R_i) \qquad (1)$$

Where, R is the one of engineering parameters such as PGA, Acc RMS, duration or pseudo acceleration response spectra (PSA). For PSA, it is calculate for each period. The index i range over the 20 scenarios. Finally, the range of engineering parameters for future earthquake are estimated by equation:

$$H_j^{\sigma} = \hat{H}_j \pm \sigma \qquad (2)$$

Where, σ^2 is the variance of the distribution of log(R) for the 20 scenarios and it is calculated for each of the parameters, separately. This estimation comes from the uncertainty on which earthquake scenario is likely to occur. Table 4 lists predicted values in horizontal and vertical components for future earthquake in Tehran.

Table 3: The limits of input parameters that are used for prediction of strong ground motions

Rupture parameters	
Slip Function	Kostrov with healing
Fault Geometry	Depth to top of rupture 1.0 km Length of rupture 35.0 km ± 10.0 km Width of rupture 16.0 km ± 7.0 km
Focal Mechanism	Strike 270o ±10.0o, dip 45.0o ± 15.0o.
Roughness percentage	is selected to be either 0, 33% of fault surface
Moment	(3.09± 0.5)*E+26 dyne-cm ≈ Mw=7
Rise Time	Dependent on Vr, Vh and hypocentre location
Shear wave Velocity	3.2 Km/s
Rupture Velocity	0.8 times the shear wave velocity
Healing Velocity	0.9 times the rupture velocity
Stress Drop	Dependent variable derived from the Kostrov slip function and moment
Rigidity Varies	With the shear wave velocity over all depths except it diminishes at the same rate as the stress drop near the surface
Slip Vector	constrained to 60,68,70,80,90o

Comparison of obtained results

Comparison with Attenuation Laws

Since no earthquake of target moment have occurred in recent years and thus no recordings are available to compare the result of the simulation with actual data, we chose to draw a comparison with attenuation laws developed for world by Campbell and Bozorgnia (2003). In order to compare parameters for the time and the frequency domain, we focus on the peak horizontal acceleration and the spectral acceleration. To compare attenuation laws and EGF computations, one must be fully aware of the inherently different nature of both approaches. The computed EGF values are not a subset of the database that could be utilized by Campbell et al (2003). Therefore, a comparison cannot verify or disprove the validity of either result. However, we demonstrate that wherever site-specific effects are relevant, specific seismotectonic scenarios are known, and the appropriate weak motion database is available, estimates of strong ground motion provided by EGF approach can differ from those using attenuation laws (Wossner et al. 2002).

Comparison of the Average Peak Horizontal Acceleration (PHA) with Attenuation Law

The PHAs of synthesized models and the attenuation law are plotted in figure5. It is obvious that the mean of models mainly fit in the σ-standard deviation range of attenuation law and also as can be seen in Fig. 5, PHA in models of 13, 14, 15, 18, 19, and 20 fit in the σ-standard deviation range. In the face of different rupture parameters input such as the position, the size of the rupture plane, dip, strike angle and the hypocentral location for these models, these models are similar in unilateral propagation toward southwest.

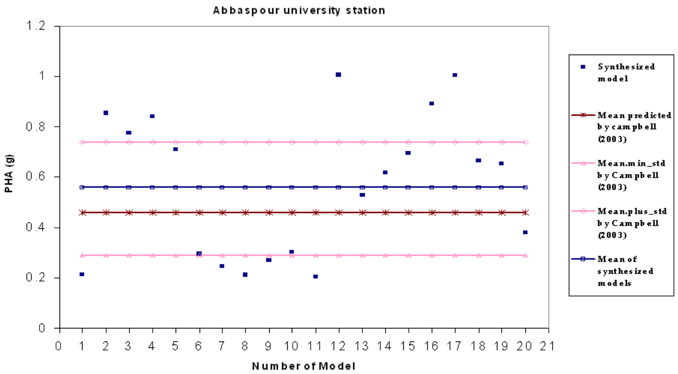

Figure 5. PHAs for all computed models in comparison with attenuation laws derived by Campbell & Bozorgnia

Comparison of Response Spectra

As a parameter from the spectral domain, we chose the response spectrum in terms of spectral accelerations to check our simulations with other derived values. We calculated response spectra (5 percent of critical damping) by means of time-integration of the equation of motion of a series of single-degree-of-freedom systems (e.g. Chopra 1995) at Abbaspour station and for all models and using the parameters given by Campbell et al (2003). As can be seen in Figure6, the response spectra computed from the synthesized accelerograms (light grey) have good agreement with the range of spectral accelerations predicted by attenuation law, also in either result peak spectral accelerations at 0.3 second is obvious. The shape of the average synthesized response spectra still fits the mean plus one standard deviation of the predicted value by attenuation law and thus represents a reasonable way to estimate the general spectral shapes even in this region without a strong motion database. Therefore, we obtained similar results with Wossner et al (2002) that they had utilized Hutchings (1991) method for prediction of response spectra for a low-seismicity region in Germany.

Comparison of Predicted Design Spectra

The influence of duration of strong motion on spectral shape has been studied by Peng et al. (1989) using a random-vibration approach to estimate site-dependent probabilistic response spectra. A comparison of the mean-plus-one-standard-deviation acceleration amplification for two different durations from that study also is presented in figure 7.

Comparison of the spectral shapes from this study by EGF method and the one recommended by SEAOC (Seismology Committee of the Structural Engineers Association of California) for soil type 2 and that proposed by Peng et al. (1989) for two durations, 10 and 20 secs, is shown in Fig.7. The spectral shapes in this figure were smoothed using four control periods.

The results in figure 7 show that longer duration of strong motion increases the response in the low and intermediate frequency regions. The duration of response spectra computed from the synthesized accelerograms is near 8 sec (Table 4) and thus this is consistent with the fact that accelerograms with long duration of strong motion have a greater probability of containing long-period waves that can result in a higher response in the long-period waves (low frequency) region of the spectrum. Also it can be seen that the response spectra computed from the synthesized accelerograms fits in the range of proposed spectral accelerations by SEAOC for soil type 2, with slightly higher values in high-period range (>1.5 s).

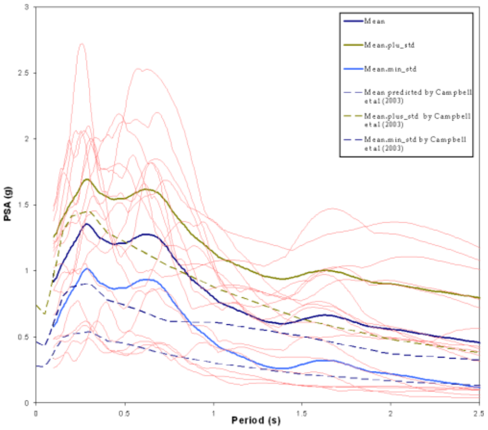

Figure 6. Response spectra at the Abbaspour station. Computed models (light grey) compared with values predicted by Campbell & Bozorgnia (2003)

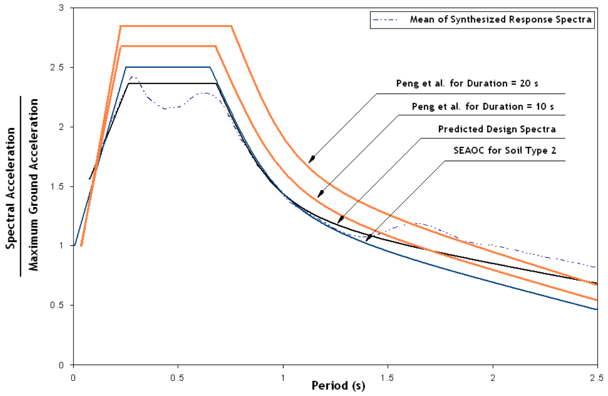

Figure 7. Comparison of spectral shapes for 5% damping proposed by SEAOC, Peng et al. (1989) with this predicted by EGF method (used in this study)

Table 4: Predicted range of engineering parameters for future Tehran earthquake

Tehran Earthquake	Mean	Mean-std	Mean+std
PGA (g)-Mean Horizontal Comp.	0.56	0.26	0.86
PGA (g)-Vertical Comp.	0.29	0.09	0.5
Acc RMS (g)-Mean Horizontal Comp.	0.072	0.024	0.121
Acc RMS (g)-Vertical Comp.	0.046	0.011	0.08
Duration (s)-Mean Horizontal Comp.	7.74	6.28	9.21
Duration (s)-Vertical Comp.	7.96	6.028	9.907

Conclusions

The purpose of this investigation was to predict acceleration time-history and a range of engineering parameters (Peak Ground Acceleration, Acceleration Root Mean Square, and Duration) and pseudo acceleration spectra in the frequency range of 0.3-25 Hz for future earthquake in Tehran. A suite of rupture scenarios was developed by defining different hypocenter location, strike, dip and slip vector, and fault plane geometries to cope with uncertainties concerning possible rupture processes. The bounds on rupture parameters are limited to what is known about the earthquake, its tectonic and geologic environment.

Comparing attenuation laws and EGF computations, one has to consider the inherent difference of both approaches. In this study, the values obtained by EGF computations are generally higher than those estimated by Campbell & Bozorgnia (2003). But it is obvious that the mean of Peak horizontal acceleration of synthesized models mainly fit in the σ ±standard deviation range of attenuation law and also, we observed that the response spectra computed from the synthesized accelerograms fits in the range of predicted spectral accelerations by attenuation law well. In addition, in either result location of peak spectral accelerations at 0.3 sec is obvious. Furthermore, the shape of the average synthesized response spectra still fits the mean plus one standard deviation of the predicted value by attenuation law and thus represents a reasonable way to estimate the general spectral shapes even in this region without a strong motion database.

Attenuation laws give a more general impression of ground motion parameters and can be used over a certain distance range. Furthermore, the data set used for deriving the attenuation law incorporates a suite of different source mechanisms and site conditions, thus leading to averaged values for a defined tectonic region. In contrast, the rupture parameters approach that has been used here is tailor-made for an estimation of ground motion parameters and pseudo acceleration spectra and design spectra at a specified source region but with a variety of rupture scenarios. The approach thus gives insight into the site-specific hazard and into the influence of rupture kinematic on ground motion.

Additionally, we compared the spectral shapes from this study by EGF method with the recommended one by SEAOC for soil type 2 and that proposed by Peng et al. (1989) for two different durations. Consequently, we found that the duration of response spectra computed from the synthesized accelerograms is consistent with the fact that accelerograms with long duration of strong motion have a greater probability of containing long-period waves that can result in a higher response in the long-period waves (low frequency) region of the spectrum. We saw the response spectra computed from the synthesized accelerograms fits in the range of proposed spectral accelerations by SEAOC for soil type 2, with slightly higher values in high-period range (>1.5 s). However, our results also show that wherever site-specific spectra become important, EGF studies represent a viable supplementary tool.

At last, it has been found the rupture parameters approach covers abroad frequency range, which is especially useful for engineering purposes and our results show that wherever site-specific spectra become important, EGF studies represent a viable supplementary tool.

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