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STRONG GROUND MOTION MODELING FOR THE 2004 FIROZABAD-KOJOOR EARTHQUAKE, NORTH OF IRAN

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SUMMARY

An earthquake with estimated magnitude of 6.2 has occurred in the North of Tehran on May 28, 2004 2:38:46 GMT. The causative fault for this earthquake wasn't known exactly based on surface geological observations. Therefore, we tried to model the rupture process by considering Kojoor fault and North Alborz fault in this area. We: 1) have studied the strong ground motion data, which recorded by Building House Research Center strong ground motion network. 2) have used M<5.0 aftershocks that occurred throughout the area and not necessarily along the fault to be modeled. 3) have simulated strong-ground-motion using empirical green function method. For this, we generated 30 models for each of these faults. It is observed based on comparison between observed and simulated records that the Kojoor fault was the causative fault for this earthquake. The comparisons were based on the ground motion parameters such as peak ground acceleration (PGA), acceleration root mean square (Acc. RMS), duration, Fourier spectra and pseudo-acceleration spectra (PSA) in all stations and for the three components. It was identified that the "best fitting" rupture models occurred in the vicinity of 36.29oN 51.602oE with center of rupture near 19 km with unilateral rupture towards North-West.

1. INTRODUCTION

Investigation of seismic waveforms in broad-frequency band is one of the most important tasks in modern seismology. The outcome from such research is indispensable for engineering seismology, which is interested in relatively high frequencies (1-20 Hz), although for large structures, e.g. skyscraper, oil tanks, suspension bridges, also long periods (< 1 Hz) are important. 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. The idea of studying large earthquakes by means of seismograms of small earthquakes, used as empirical Green's function (EGF), was introduced initially by [Hartzell, 1978, and Wu, 1978]. Later methods proposed by [Hadley & Helmberger, 1980; Irikura, 1983; Wald et al, 1988; Joyner & Boore, 1986; Boatwright, 1988; Wennerberg 1990; Hutchings et al, 1990; Aki & Irikura, 1991] are modifications of EGF's method. In empirical Green's function approach rupture propagation and radiation pattern were specified deterministically and the source propagation and radiation effects were included empirically by assuming that the motions observed from aftershocks contained this information [Somerville et al., 1991].

The EGF method used here can be applied both in inverse and direct problems. In the inverse problems, EGF method helps to retrieve the focal mechanism and the source time function, to determine the moment tensor, or to find the rupture parameters or the slip distribution on fault [Mueller, 1985; Mori and Frankel, 1995; Hutchings, 1991; Velasco et. al., 1994].

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‘Rupture parameter approach‘ [Hutchings, 1991] used in this study only requires that the number of small earthquakes used in the synthesis is such that the sum of their moments adds up to the moment of the large earthquake, which matches the low frequency of observed seismograms. The high is matched simply by using appropriate rupture parameters.

The Firoozabad-Kojoor earthquake was located between the north Alborz fault and Kojoor fault but causative fault for this earthquake wasn’t known exactly base on surface geological observations.

We have studied the strong ground motion data, which recorded by Building House Research Center strong ground motion network. For this, we have used M<5.0 aftershocks that occurred throughout the area and not necessarily along the fault to be modeled. Finally, we have simulated strong-ground-motion using empirical green function method. For this, we defined 30 models for each of these faults and based on pervious studies of this area. We determined that one of our source models on the Kojoor fault generates records that match observed time histories well; the comparisons were based on ground motion parameters such as peak ground acceleration (PGA), acceleration root mean square (Acc. RMS), duration, and Fourier spectra and pseudo acceleration spectra (PSA) in all stations that recorded EGF’s event and for the three components. So, we found that Kojoor fault was the causative fault for this earthquake.

2. METHODOLOGY

The summation of the small events (EGFs) is thus based on scaling relations between small and large events. The number of sub events or EGFs is N3, where the scaling parameter N is an integer value determined as the ratio of the moment of the target event and the moment of the small event. Because this number is relatively small, the discretization of the rupture process is quite coarse, which produces high-frequency spatial and temporal aliasing effects [Bour & Cara, 1997]. On the other hand, a lack of high-frequency content above the corner frequency of the EGFs results in deficiencies in the high-frequency part of the large event. Therefore, some approaches [e.g. Wennerberg, 1990] use random summation to artificially generate high frequencies.

In contrast, ‘the rupture parameter approach ‘[Hutchings, 1991] requires very small events (Mo<1.5*10^14 Nm). 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 & Wu, 1990]. The actual rupture process is simulated by adding up EGFs using a kinematic rupture a model. Therefore, the fault plane of the target event is discretized into elemental area (Fig.1) that are small enough to model continuous rupture up to the highest frequency of interest. The sum of the moments of all elements matches any arbitrary given target moment.

In this study, rupture parameter approach [Hutchings, 1991] has been used with a difference; we used M<5 events instead of very small events.

In this approach, Green’s functions for each portion of the fault are calculated and convolved with source functions at each point along the rupture surface. Here, we use empirical Green’s functions and synthesize ground motion from 0.3 to 25.0 Hz. Because of, there are more available and the signal to noise is better for recorded earthquake. In order to use M<5 events instead of very small events, impulsive point shear source empirical Green’s functions were generated by deconvolving out the source contribution of moderate earthquakes.

3. FIROOZABAD-KOJOOR EARTHQUAKE

On May 28, 2004, at 12:38:46 Coordinated Universal Time, UTC, (17:8:46 local time scale), a major earthquake with estimated Mw 6.2 occurred near the northern part of Iran.

The moment magnitude from main shock of this earthquake that has been reported by USGS, and HRVD are listed in Table 1. Figure 2 shows location of epicenter that has been reported by IIEES, HRVD, BHRC, EMSC, USGC, RMES, NEIC, and they are listed in Table 2. Figure 3 shows the isoseismal intensity from the 2004 Firozabad-Kojoor earthquake. Also shown on Figure 4 are names and locations of stations used in this study.

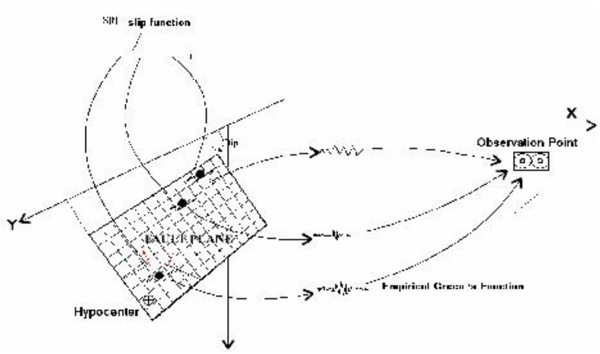

Figure 1: Scheme of EGF summation (rupture parameter approach)

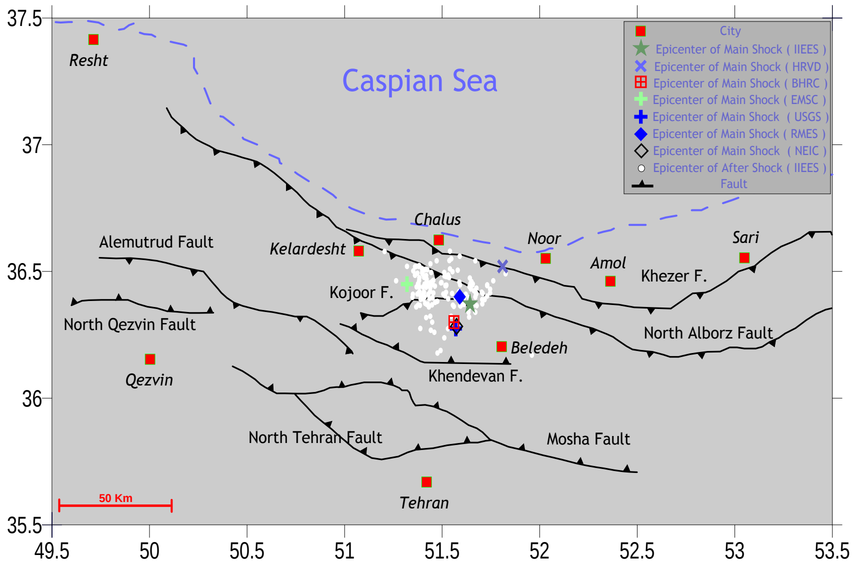

Figure 2: Location of epicenter reported by IIEES, HRVD, EMSC, USGC, RMES, NEIC, and location of aftershocks

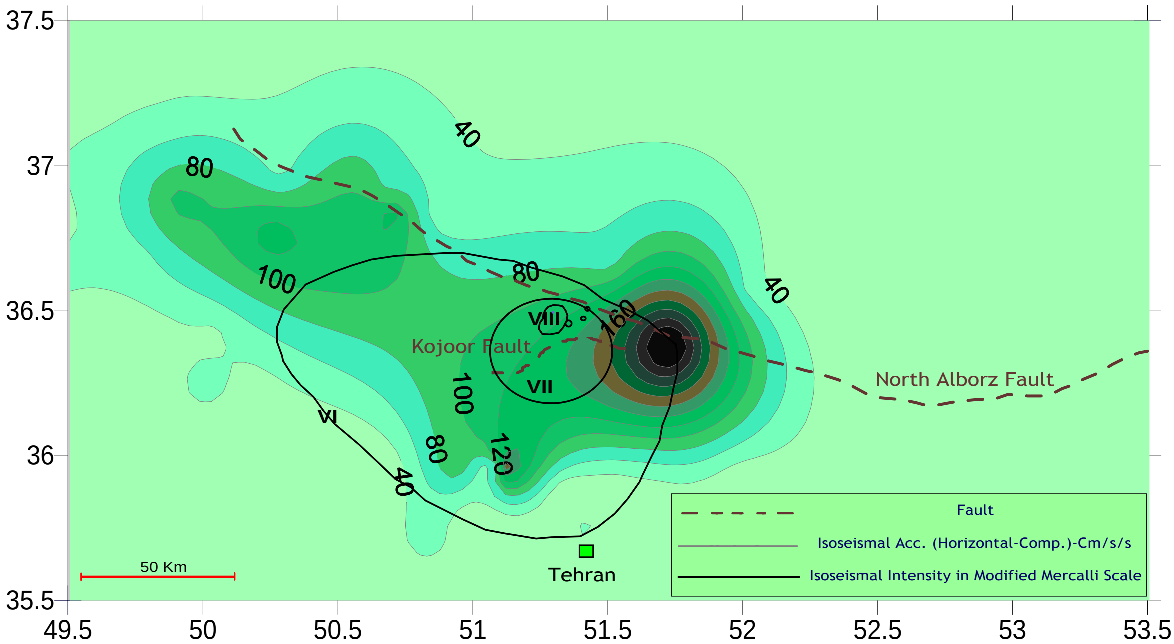

Figure 3: Isoseismal intensity from the 2004 Firoozabad-Kojoor earthquake in Modified Mercalli Scale, and location of north Alborz fault and Kojoor fault

Table 1: USGS and Harvard, moment tensor solution of 2004 Firoozabad-Kojoor earthquake

	Mw	Mo (dyne.cm)	Strike	Dip	Slip
HARVARD	6.3	3.31E+25	116	32	69
USGS	6.2	2.50E+25	100	43	67

Table 2: Magnitudes, Focal depth and Epicenter for the 2004 Firoozabad-Kojoor earthquake, reported by earthquake research centers

No.	Reference	EP Coordinate		ED (km)	mb	Ms	Mw	Ml
		E	N					
1	IIEES	51.643	36.371	28	-	6.3	6.2	-
2	HRVD	51.81	36.52	34.7	6.2	6.2	6.3	-
4	USGS	51.57	36.275	14	-	-	6.2	-
5	NEIC	51.574	36.283	28.3	-	-	6.2	-
6	EMSC	51.32	36.45	40	6.2	-	-	-
7	BHRC	51.56	36.3	-	-	-	-	6.1
8	RMES	51.59	36.4	25	-	6.3	-	-

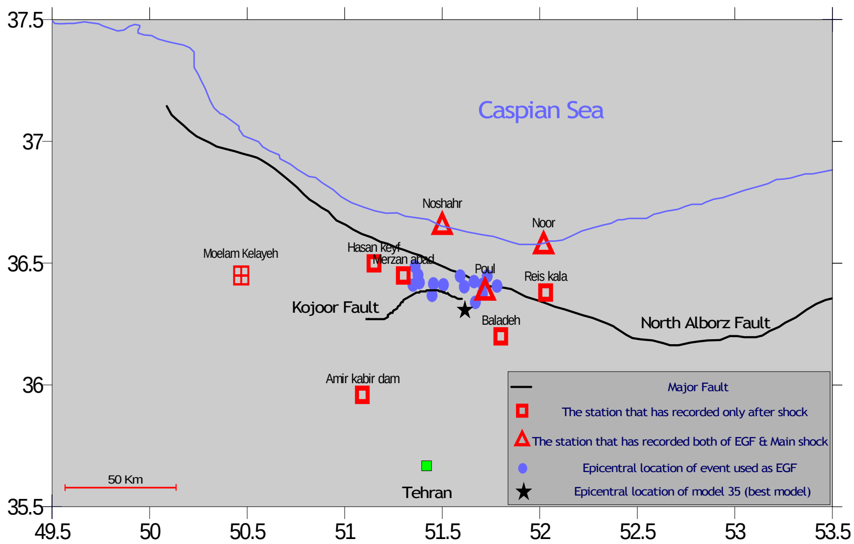

Figure 4: The locations of stations and epicentral location of event used in this study, and epicentral location of the best synthesized model that match observed main shock

3.1 Strong Motion Data

The 2004 Firoozabad-Kojoor earthquake has been recorded by 138 stations. All the instruments are of SSA-2 type with threshold of 10 gals. Out of these 138 stations, only 3 stations, which recorded both of main shock and some of aftershocks, have been considered. Table 3 lists the salient feature of these 3 stations while their locations are shown in Figure 4.

Table 3: Coordinate and soil type of recording station, azimuth of two horizontal components

Station	Record No	Geographical Coordinates		Azimuth		Soil Type
		E	N	L	T	
Pool	3330	51.72	36.38	220	310	Group 2
Noor	3369	52.02	36.57	355	85	Group 3
Noshahr	3368	51.5	36.65	112	202	Group 3

3.2 Site Effect

The site classes are estimated based on the transfer function method, in which the H/V amplification function is calculated, in order to find the fundamental frequency of the site (Zare et al 1999).

The formulation used for the H/V method is based on the spectral ratio (R_{HV}) between the smoothed horizontal components and the smoothed vertical component. Since the same time windows are used the same for all of the components, this relationship might be simplified as:

$$R_{SN} = \frac{\frac{1}{2} \times (SH_1(f) + SH_2(f))}{SV(f)} \tag{1}$$

As discussed in Zare et al. (1999): in brief ,site category 1 corresponds to rock and hard alluvial site, with average *Vs<800m/s* over the top 30m and site amplifications (SAM) beyond 15Hz. The site category 2 relates to alluvial sites; thin soft alluvium, with *500<Vs<700m/s* over the top 30m, and *5<SAM<15 Hz*. The site category 3 corresponds to soft gravel and sandy sites, with *300<Vs<500m/s* over the top 30m and *2<SAM<5 Hz*. Finally the site category 4 relates to soft soil site; thick soft alluviums with *Vs<300m/s* over the top 35m and *SAM<2Hz*.

According to section Determination of the Appropriate Frequency Band, acceptable threshold level of 3 for signal to noise is selected to delimitate the frequency band. Site amplification (SAM) is estimated where signal to noise ratio is acceptable and the soil type of studied stations has been listed in Table 3.

3.3 Determination of the Moment Magnitude of Events

The moment magnitude was systematically calculated by for all of the aftershocks, which are well recorded after shocks.

The source model used to estimate the moment magnitude in this study is based on [Haskell, 1964], who proposed a simple source model for the estimation of high frequency ground motions. [Aki, 1967; Brune, 1970; and Brune, 1971] explained the simple seismic source models. In this model, the displacement spectrum is characterized by a flat level proportional to M_o at long periods, a corner frequency f_c proportional to inverse of the source dimension, and a high frequency spectral decay in the form $(f / f_c)^{-¥}$.

The scale with taking into account the coefficients for N-m unit of M_0, could be written as defined by [Hanks and Kanamori, 1979]:

$$M_w = 0.667 \cdot \log M_0 - 6.0 \tag{2}$$

Table 4: Hypocentral coordinates and moment magnitude for the EGF's used for synthesized main shock at the stations of Pool, Noor, and Noshahr.

POOL	Latitude (O)	Longitude (O)	M_w
040528131507	36.45	51.59	4.6
040528133556	36.40	51.61	4.4
040528194705	36.37	51.45	4.8
040529092351	36.41	51.35	4.7
040530014241	36.40	51.61	4.5
040530192702	36.42	51.66	4.6
040607040123	36.41	51.51	4.1
NOOR	Latitude	Longitude	M_w
040528131507	36.45	51.59	4.6
040529092351	36.41	51.35	4.7
040530014241	36.40	51.61	4.5
040530192702	36.42	51.66	4.6

Table 4: continues;

NOSHAHR	Latitude	Longitude	M_w
040529092351	36.41	51.35	4.7
040530014241	36.40	51.61	4.5

4. CONSTRUCTING RUPTURE SCENARIOS

In this study, earthquake rupture models rely on the position, the size of the rupture plane, the hypocenter, the rupture velocity, the healing velocity, rupture roughness and slip parameters (final displacement and rise time, or a slip distribution model for which these values are derived). The downward extension of rupture plane has been estimated on the basis of aftershocks. The aftershocks extended in depth ranging from 1 to 43 km with most of the activity occurring between 15 to 28 km.

Rupture parameters are selected randomly. Also, 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 are utilized.

4.1 The best Rupture Model

Strong-motion synthetics were generated for each rupture scenario at the stations that recorded both of main shock and aftershocks, and then it was tested whether one of the 60 models provides ground motions that match the observed spectra and engineering parameters of the Firoozabad-Kojoor earthquake at these stations. Our basic assumption is that if accelerograms give a good fit to observed records, then the rupture model is near what actually happened.

We determined that one of our source models on the Kojoor fault generates records that match observed main shock well; the comparisons were based on ground motion parameters and Fourier spectra and pseudo acceleration spectra for three components and in all stations that recorded EGF's event.

So, we found that Kojoor fault was the causative fault for this earthquake. It was identified that the "best fitting" rupture models occurred in the vicinity of 36.29oN 51.602oE with center of rupture near 19 km with unilateral rupture towards North-West.

Table 5: Compression of extracted parameters from best model (model 35) and observed records

POOL Best Model							
	PGA (Cm/s/s)	Acc. RMS (Cm/s/s)	Duration (s)	Observed Main Shock	PGA (Cm/s/s)	Acc. RMS (Cm/s/s)	Duration (s)
Comp. 220	297.5	30.7	4.65	Comp 220	290.13	37.92	5.025
Comp. 310	141.082	19.1057	4.505	Comp 310	158.72	25.35	5.01
Comp. z	194.93	27.85	5.7	Comp z	254.96	23.747	5.235
NOOR Best Model							
	PGA (Cm/s/s)	Acc. RMS (Cm/s/s)	Duration (s)	Observed Main Shock	PGA (Cm/s/s)	Acc. RMS (Cm/s/s)	Duration (s)
Comp. 355	55.7	10	9.365	Comp 220	48.967	8.97	12.3
Comp. 085	42.56	9	11.715	Comp 310	60.8	9.38	11.6
Comp. z	26	4.9	13.995	Comp z	18.259	3.89	20.88
NOSHAHR Best Model							
	PGA (Cm/s/s)	Acc. RMS (Cm/s/s)	Duration (s)	Observed Main Shock	PGA (Cm/s/s)	Acc. RMS (Cm/s/s)	Duration (s)
Comp. 112	85.87	18	12.54	Comp 220	66.86	11.37	11.8
Comp. 202	109.94	18.64	10.455	Comp 310	103.76	12.53	7.035
Comp. z	49.25	10.587	14.69	Comp z	35.57	5.19	13.57

5. CONCLUSION

The purpose of this investigation is to test the rupture parameter approach proposed by Hutchings (1991) in the frequency range of 0.3-25 but with a difference. We used M<5 events instead of very small events. For this, we generated impulsive point shear source empirical Green's functions by deconvolving out the source contribution of M<5.0 weak events. The causative fault for this earthquake wasn't known exactly based on surface geological observations. For this, we defined 30 models for each of these faults and based on pervious studies of this area. In the thirty scenarios tried, only one combination of source parameters on the Kojoor fault plane gave a good fit for all the three stations and for three components in comparison with other models. So, we found that Kojoor fault was the causative fault for this earthquake and furthermore, the rupture parameters of this scenario are near what actually happened. So, we found that rupture occurred in the vicinity of 36.29oN 51.602oE with center of rupture near 19 km with unilateral rupture towards North-West. The results obtained give a validation of this strong ground motion synthesis methodology as a capable technique to predict reasonably well the observed records.

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