Modification of seismological parameters of Zarand earthquake (2005 February 22), in central Iran, Using Empirical Green's function method

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Abstract:

The main purpose of this article is to modify the seismological source parameters such as, fault plane orientation/geometry, nucleation point, stress drop, maximum slip, average slip and source duration of 2005 February 22 Zarand earthquake located at the central part of Iran. The Zarand source parameters have already been studied by another investigators using radar interferometry. We used the Empirical Green's Function approach for simulating the strong motions recorded at three stations far away from the source so that not being influenced by near source effects such as directivity. The Kostrov slip model describing the entire rupture process has been incorporated in the model. The synthesized strong motions and also the 5% response spectrum of the strong motions at three stations (each of which with three components), are compared with those of the recorded data. Good much of synthesized response spectra with those of observed data confirm the potentiality of the used technique in stimulating the strong motion and the reliability of the selected source-path parameters and site soil conditions.

Keywords: Zarand earthquake, empirical green's function, kostrov slip model, synthesized strong motion , fault plane orientation and geometry, stress drop, source maximum slip, average slip and source duration.

1- Introduction

In nonlinear dynamic analysis of structures, realistic time histories are preferred to be used for reducing uncertainties in estimation of standard engineering parameters. The synthesized strong motions have been used as input data for the evaluation of earthquake resistant design criteria by Irikura (Irikura 1983).).

The first successful attempt for theoretical calculation of strong motions was made by Aki (1968) and Haskell (1969). Kinematic source model was used by propagating dislocation over a fault plane in an infinite homogeneous medium. The approach they proposed, essential for a deterministic fault model, contains source parameters such as, fault length, fault width, rupture velocity, final offset of dislocation and rise time.

Sato and Hirata (1980) gave a new approach using integral evaluation to compute the seismic motions for layered media including the contributions from dispersive surface waves.

A different approach for estimating strong motions proposed by Aki, is based on inhomogeneous fault models such as barrier model and asperity model (Aki, l979).

2- Green's Functions

Another approach to synthesize strong motions was first proposed by Hartzell (1978), utilizing observed seismograms from small events as Green functions. It is a most advantageous method because the Green functions include complex effects of the dynamical rupture process on the fault as well as heterogeneous structures around the source and an observation site, which are extremely cumbersome to evaluate. . It was subsequently used and developed by some investigators like Mueller (1985), Fukuyama and Irikura (1986), Mori and Frankel (1990), Hutchings (1991), Ammon et al. (1993), Velasco et al. (1994), Courboulex et al. (1997a), and Ihmle´ (1996). The idea is to deconvolve the main shock from the smaller event, called the empirical Green function (EGF).

Hutchings (1991) proposed empirical Green's functions to constrain propagation path and site response information and a range of simple kinematic rupture models to describe the source in predicting strong ground motion for the full time history. He proposed simple kinematic rupture models relying on moment, fault geometry, hypocenter location, slip function, rupture velocity, and healing velocity and rise time. Empirical Green's functions include the actual effects of velocity structure, attenuation, and geometrical spreading. However, it is not possible to record empirical Green's functions from all locations along a fault of interest and with the same focal mechanism solution, so that source locations of empirical Green's functions are interpolated to fill in the fault.

Hutchings and Wu (1990) found that, the variability in ground motion due to differences in source location and/or focal mechanism solutions are much less than that due to the site response. Hutchings (1991, 1994), and Jarpe and Kasameyer (1996) found that, interpolation for different source locations along a fault works quite well. Hutchings believes that, it is not necessary to have source events directly along the fault but near the fault of interest.

2- EMPIRICAL GREEN'S FUNCTIONS

The basic assumptions in empirical Green's functions are firstly that, they are effectively from step-impulsive point-dislocation sources over the frequency range of interest so that spectral shapes and the time series are primarily a result of propagation of path and site effects, secondly, they can be interpolated for source locations where small earthquakes did not occur or for different focal mechanisms. Their recording site geology has the same linear elastic response for weak ground motion recorded from small earthquakes and strong ground motion from large earthquakes.

In this study we used the discredited representation relation with empirical Green's functions (EGF) in the form of:

$$u_n(X,t)=\sum_{i=1}^{N}\frac{\mu_i A_i S(t')_i}{M^e_{0i}} * e_n(X,t'-t_r)_i \qquad (1)$$

Where $U_n(X, t)$ in equation *(1)* is the displacement corresponding to position X, time t, in space relative to the hypocenter, A_i is an elemental area such that $\sum A_i$ equals the total rupture area, μ_i is the rigidity at an element, $S(t')_i$ is the desired slip function at an element, $e_n(X, t'-t_r)_i$ is the recording of a small earthquake with effectively a step source time function and interpolated to have a source and origin time at the location of the i_{th} element, t' is the time relative to the origin time of the synthesized earthquake, t_r is the rupture time from the hypocenter to the element, which is the integral of radial distance from the hypocenter of the synthesized earthquake divided by the rupture velocity,. M^e_{0i} is the scalar seismic moment of the source event, and * is the convolution operator. U_n has the same units as e_n.

We have used the FORTRAN program EMPSYN, originally written by Hutchings (Hutchings & Wu 1990; Hutchings 1991), which numerically estimates synthetic seismograms. EMPSYN uses a summation of step functions to model the Kostrov or Haskell slip functions in time domain. We used Kostrov slip function with Healing Phases proposed by Hutchings. The time delay for the step functions' summation is at the digital sampling rate of the EGFs to ensure that high-frequency artifacts are higher than the frequency range of interest. In the frequency domain, EMPSYN employs a ramp function with all the parameters of the Kostrov or

Haskell slip functions. Hutchings (1994) showed that the difference in computed seismograms using the ramp to model the shape of the Kostrov slip function was indistinguishable in the frequency range of 0.5 to at least 15.0 Hz.

3- TECTONIC SETTING AND SEISMICITY

The active tectonics of Iran are dominated by the convergence of the Arabian and Eurasian plates which, according to GPS data, occurs at about 22 ± 2 mm/yr in the direction N13◦E (Vernant et al. 2004).

This is ~10 mm/yr lower than the rate previously suggested from analysis of global seafloor spreading, fault systems and earthquake slip vectors (DeMets 1994). Deformation and hence seismicity is concentrated at the boundaries of relatively aseismic blocks such as central Iran and Lut (Berberian et al. 2001; Walker & Jackson 2002). The Gowk fault is a part of the west side boundary of the Lut block, and is oriented NW–SE with a right-lateral strike slip sense of motion. The direction of maximum principal horizontal stress in the area is about N8◦E (Vernant et al. 2004).

Although the area has a long record of the damaging historical earthquakes going back about 1000 yr (Ambraseys & Melville 1982), reliable instrumental recordings of seismicity only started in the 1960s. The northern part of the Gowk fault has been quite active since the early 1980s, producing three consecutive M ≥ 6.6 earthquakes. More recently a moderate size event (M = 6.4) occurred NW of the Gowk fault in 2005 February with reverse slip on an approximately E–W striking fault.

On 2005 February 22 an earthquake of Mw 6.4 struck a region of south–central Iran near Zarand, about 60 km north of the city of Kerman, the provincial capital (Fig. 1).

The earthquake occurred at 05:55 am local time, in winter, so many people were indoors, and Casualties were high in the villages affected, with approximately 500 killed in Dahuiyeh and Hotkan. Iran Strong Motion Network (ISMN) was recorded by 27 set of SSA-2 digital accelerographs. The maximum peak ground acceleration as much as 510.09 gals was recorded at the Shirinrood Dam station. This paper is concerned with synthesized main earthquake in two stations via Empirical Green's function model.

On Feb. 22, 2005 at 02:25:26 (UTC) a destructive earthquake (Mw 6.3 NEIC) occurred of east of Zarand city in Kerman province, SE Iran. Up to this moment, Iran Strong Motion Network (ISMN) was recorded by 27 set of SSA-2 digital accelerographs. The maximum peak ground acceleration as much as 510.09 gals was recorded at the Shirinrood Dam station. The epicenter of the earthquake has been located at 30.804N, 56.734E (BHRC), 30.79N, 56.90E (IGTU) and 30.75N, 56.80E (NEIC), 30.73N, 56.79E (EMSC).

The 2005 Dahuiyeh earthquake did not rupture the Kuh Banan fault, but occurred on an E–W reverse fault within the mountainous region to the east (Fig2).
As refer to Talebian et al, it had a northward dip of 60◦–65◦, which is steep even for reverse faults. Its epicenter is about 10–15 km west of an earlier, smaller (Mw 5.3) earthquake in 1984 August 6 with a reverse-fault mechanism which causes great damage to Hur village.
The Zarand source parameters, such as focal mechanism, source depth, magnitude, rupture length and rupture area, previously estimated by other investigators, are

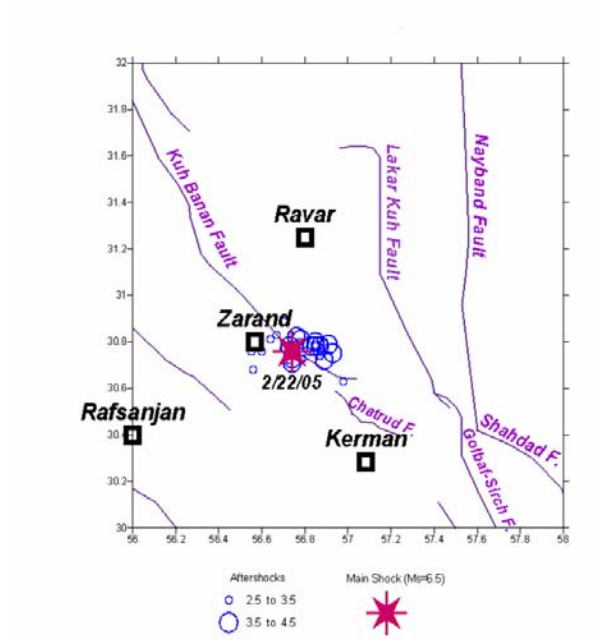

Figure 1 Main shock near Zarand (22/02/2005) and it's aftershocks (35 aftershocks)

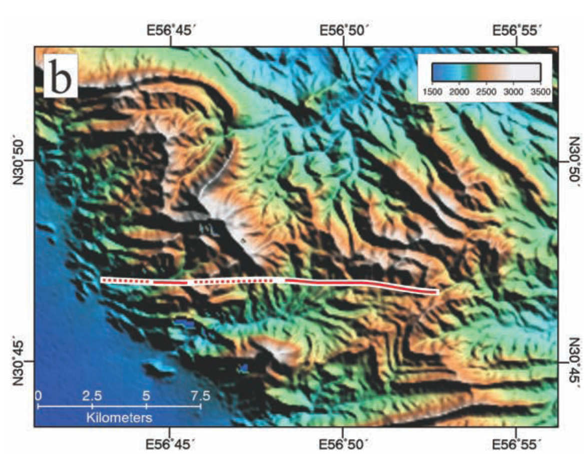

Figure 2 The coseismic rupture in the 2005 Dahuiyeh earthquake is marked by the red line (after Talebian et al 2005)

again estimated using the Empirical Green's function approach. For the purpose of comparing our estimated source parameter values with those of others, the results are presented in Table 1. In order to, a weighted average value of source parameters, as shown in Table 2, is incorporated in the model 2 for reducing the uncertainties inherently existing in such parameters. Note that more weighted values of Talebian's data were used because his individual research works in Dahuiyeh station.

Table 1. Summary of source parameters for the earthquakes shown in Fig.1

Longitude Degree	Latitude Degree	Depth (Km)	Moment Mw	Focal mechanism (STK DP SV)	Reference
56.734	30.804	10	6.4	--	BHRC
56.9	30.79	--	6.4	261 , 51 , 97	IGTU
56.801	30.75	42	--	279 , 46 , 124	NEIC
56.79	30.73	--	--	--	EMSC
56.74	30.76	--	6.4	--	IEES
56.736	30.774	7	6.4	270 , 60 , 104	Talebian et al
56.76	30.764	10	6.4	270 , 60 , 104	This study (Used)

Table 2. Fault dimensions proposed by different investigators and corresponding weights.

	Shimizaki(1975) weight 25%	Wells & Copersmith weight 25%	Talebian et al weight 50%	This study (Used)
Rupture Length	16.9 km	19.6 km	12.5 km	15.4 km
Rupture Width		11km		11km
Rupture Area		215.6 km^2		169.4 km^2

4- Source Data

It is not possible to record empirical Green's functions from all locations along a fault of interest with the same focal mechanism solution. The source location of empirical Green's functions have been interpolated to fill the sub-fault of fault plain. Interpolation is performed by correcting the attenuation law l/R, and P-, S-wave arrival times due to differences in source distance. We included the radiation pattern effect for low frequencies, when using synthetic Green's functions.

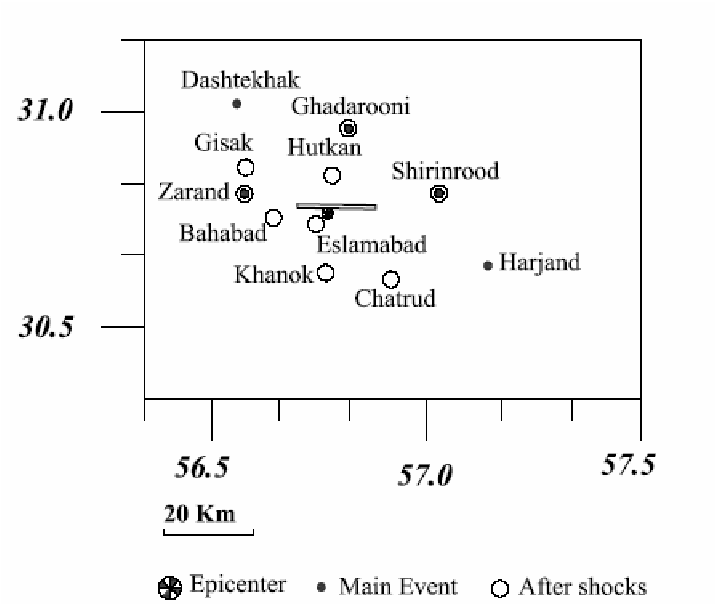

Figure 3 **locations of epicenter, main shock and stations at which the after shocks were recorded during the 2005 Zarand earthquake**

Digitized three-component recordings of aftershocks from the 2005 Dahuiyeh earthquake were obtained by BHRC at stations where strong ground motions due to the main event were recorded. It is worth mentioning that, the selected stations were sufficiently far away from source (more than 25 kilometer) so that they had not been influenced by near source effects such as directivity and fling step. Figure 3 shows the locations of epicenter, main shock and stations at which the after shocks were recorded during the 2005 Zarand earthquake.

Table 3 shows the recording site stations, Ghadarooni Dam, Shirinrood Dam, Zarand, Eslamabad, Hutkan and Khanok. The corresponding longitude, orientation and the number of recorded aftershocks are also presented. The site soil conditions, shown in the Table 3, are classified according to the Iranian standard No. 2800, which is compatible with those of NEHRP Code. Table 4 shows the stations, earthquake longitude/latitude, depths, magnitudes and references of aftershocks used for simulating strong motions at each station using Empirical Green's function approach.

5- Crustal Model

The crustal linearly increasing velocity model proposed by Haddon (1995) is adopted in this study for determining rupture and healing velocity during source rupture and for interpolation process of empirical Green's functions.
The velocity model is approximated by:

$V_p = 4.5 + 0.05*Z$, where Z is depth with $V_p = 6.0$ at 30.0 km;

5-1- Modeling and result

We simulated the main strong ground shaking using empirical Green's functions approach for frequencies ranges from 0.40 to 25.0 Hz. Most of the weak events we used have moments greater than the threshold identified by Hutchings & Wu (1990). Three stations Zarand, Ghadarooni, and Shirinrood were selected as the bench mark for validating the simulated strong motions. The source seismic moment M_0=4.470E+25 dyne-cm was calculated based on the empirical relation proposed by Kanamori (Kanamori, H. and Anderson, D. L., 1975).

In order to create EGFs, we used the selected output after shock source parameters and deconvolve out the finite Brune source correction from the recordings (Hutchings 2007). The obtained results are summarized in table 5.

The simulated strong motions and elastic response spectra at three stations are compared with those of recorded data. Figures 5&6 show the comparison of the observed acceleration time-history to those of synthesized seismograms for stations Zarand and Ghadarooni for each component (L., T. and V. orientation). As it can be seen, good agreement between synthesized strong motion and those of recorded data confirms the reliability of the model and the selected seismological source-path and site parameters for the region.

Table 4. the stations name, earthquake longitude/latitude, depths, magnitudes and references of aftershocks used as Empirical Green's functions for stations.

	Eve. Name	Earthquake Date and Time	Longitude	Latitude	Depth (Km)	Ml	Mn	reference
Ghadarooni	3689/05	2005/02/22	56.88	30.95	20		4.8	IGTU
	3689/07	2005/02/22	56.91	30.79	16	3.8		IIEES
	3689/08	2005/02/22	56.85	30.78	14	4.2		IIEES
Shirinrood	3689/05	2005/02/22	56.88	30.78	15	4		IIEES
	3697/04	2005/02/22	56.91	30.79	16	3.8		IIEES
	3697/05	2005/02/22	56.85	30.78	14	4.2		IIEES
Zarand	3711	2005/02/22	30.75	56.74	14	3.8		IIEES
	3693/01	2005/02/22	30.74	56.74	14	3.5		IIEES
	3693/03	2005/02/22	30.71	56.74	18	3.7		IIEES

Table 5 **The results obtained form EMPSYN FORTRAN Program**

Maximum slip	Rise time	Average slip	Source duration	Stress drop
111.24cm	3.21 s	80.1cm	5.06s	44.6 bars

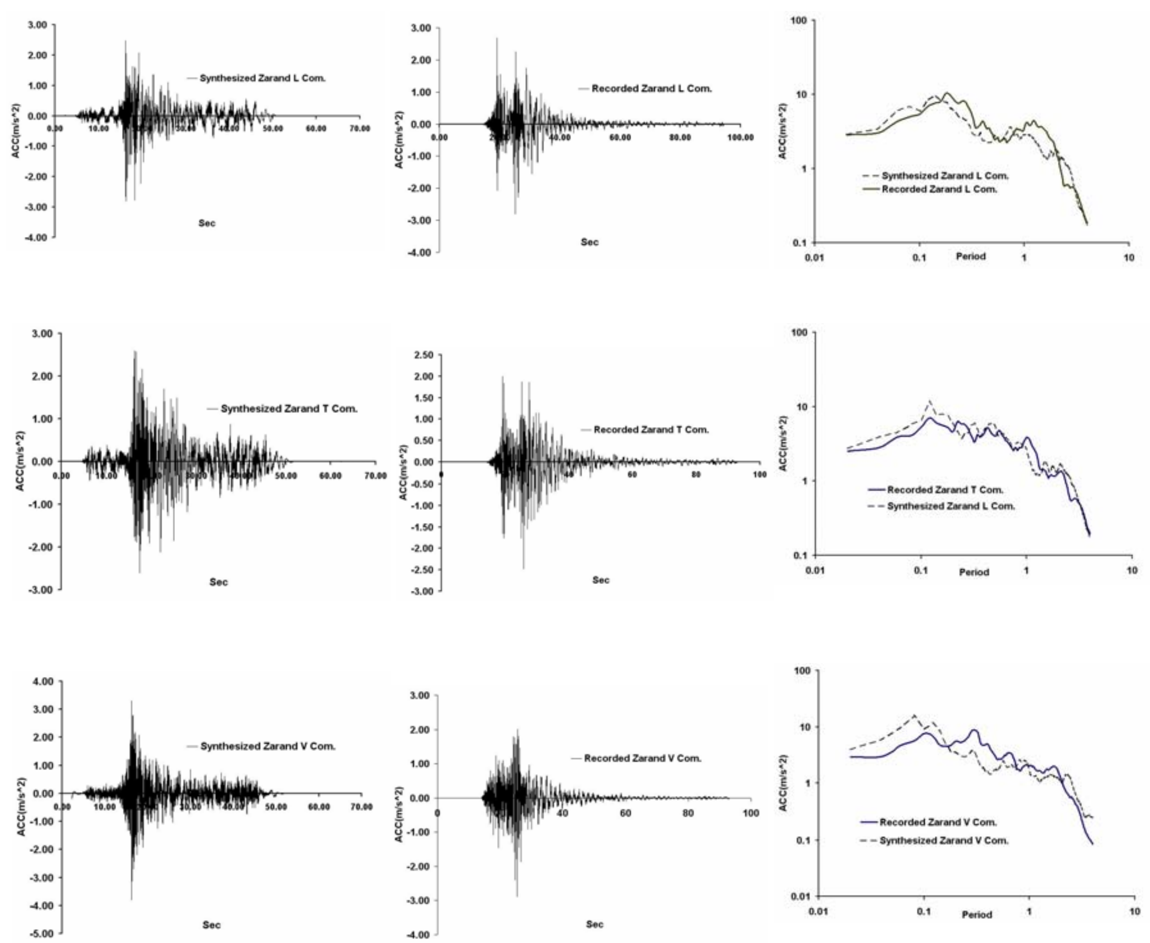

Figure 5 **Comparison of sensitized strong motions and elastic response spectra at station Zarand with those of recorded data.**

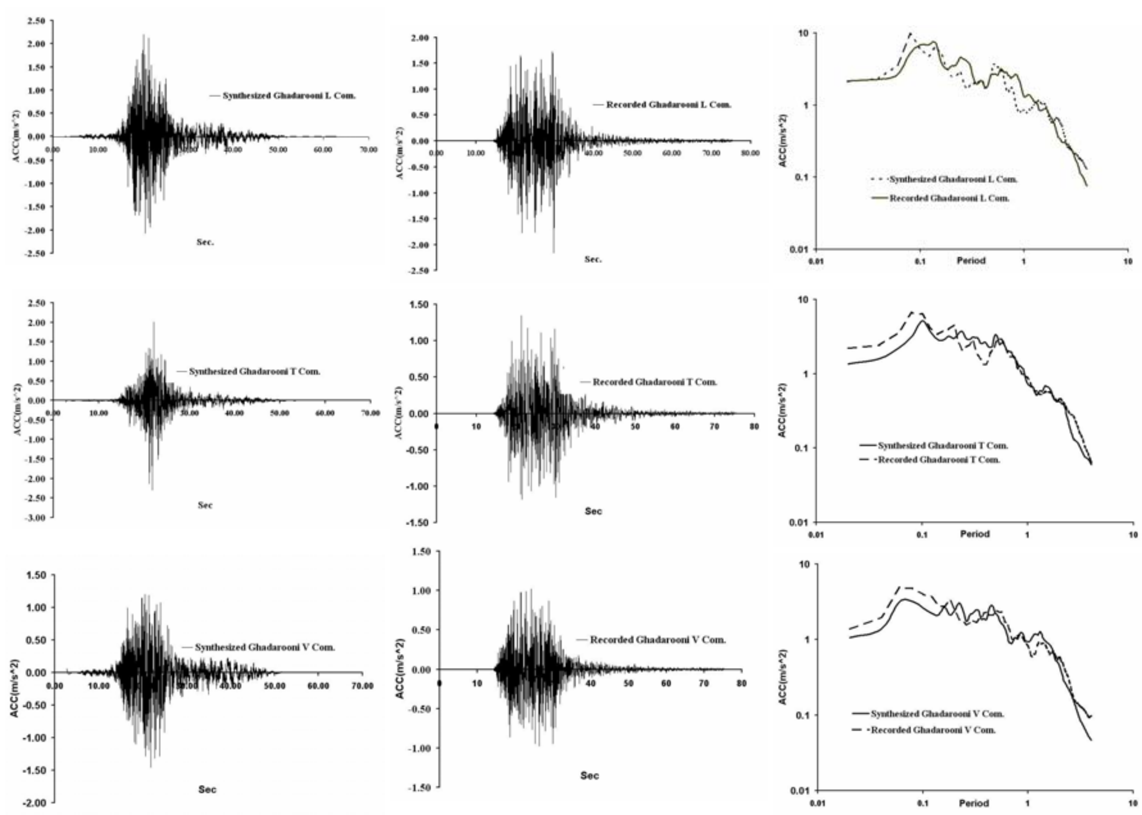

Figure 6 Comparison of sensitized strong motions and elastic response spectra at station Ghadarooni with those of recorded data.

6- Conclusion

We simulated the strong ground motion of Zarand earthquake, 2005, recorded at three stations around Zarand city. The selected stations are sufficiently far away (more than 25 kilometer) from source so that the records have not been influenced by near source effects such as directivity and fling step factors. It is not claimed that the results of this study is quite accurate and the whole seismological factors are incorporated in the model because of many reasons such as constant stress drop assumption which in fact is a dynamic problem and variable through the rupture length. Rather, we claim that, the selected source-path model parameters and also the site soil conditions were sufficiently acceptable to be used in hazard analysis of engineering problems for the region. More over, In spite of the viewpoint of Hutchings, we used the aftershocks having the magnitudes around 3.5 to 4.3 due to the noise-to-signal problems which may cause considerable discrepancy. We observed, through the simulation procedure, that, more accurate results can be obtained using more aftershocks records (EGFs), which seems to be natural due to the fact that, more realistic small events are used.

7- Acknowledgments

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