

# FINITE FAULT MODELING OF FUTURE LARGE EARTHQUAKE FROM NORTH TEHRAN FAULT IN KARAJ, IRAN

Meghdad Samaei<sup>1</sup>, Masakatsu Miyajima<sup>2</sup>, Hamid Saffari<sup>3</sup>, Masato Tsurugi<sup>4</sup>

<sup>1</sup> Doctoral Student, Graduate School of Natural Science and Technology, Kanazawa University  
Kakuma-machi, Kanazawa, Japan. samaei@stu.kanazawa-u.ac.jp

<sup>2</sup> Professor, Graduate School of Natural Science and Technology, Kanazawa University  
Kakuma-machi, Kanazawa, Japan. miyajima@t.kanazawa-u.ac.jp

<sup>3</sup> Doctoral Researcher, Graduate School of Natural Science and Technology, Kanazawa University  
Kakuma-machi, Kanazawa, Japan. hamid.saffari@gmail.com

<sup>4</sup> Senior researcher, Geo-Research Institute

4-3-2, Itachibori, Nishi-ku, Osaka, Japan. tsurugi@geor.or.jp

The main purpose of this study is to predict strong ground motions from future large earthquake for Karaj city, the capital of Alborz province of Iran. This city is an industrialized city having over one million populations and located on near several active faults. Finite fault modeling with a dynamic corner frequency has adopted here for simulation of future large earthquake. Target fault is North Tehran fault with the length of 110 km and rupture of west part of the fault which is closest to Karaj, assumed for this simulation. For seven rupture starting points, acceleration time series in the site of Karaj Caravansary –historical building- are predicted. Peak ground accelerations for those are vary from 423  $\text{cm/s}^2$  to 584  $\text{cm/s}^2$  which is in the range of 1990 Rudbar earthquake ( $M_w=7.4$ ). Results of acceleration simulations in different distances are also compared with attenuation relations for two types of soil. Our simulations show good agreement with one of the most well known world attenuation relations in all distances and show a good agreement with one of the attenuation relations that have developed for Iranian plateau in distances less than 100 kilometers.

**Key words:** Strong ground motion prediction, Finite fault modeling, Karaj, North Tehran fault

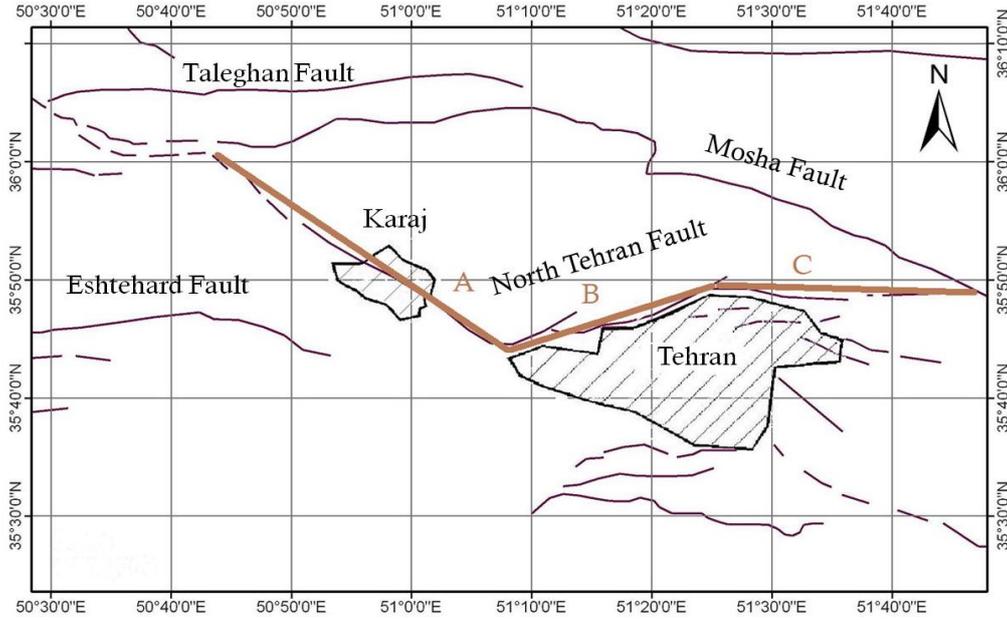
## 1. INTRODUCTION

Karaj city, the capital of the Alborz province with the population of 1,377,450 in the 2006 census, is the fifth-largest city in Iran. However, this city is increasingly becoming an extension of metropolitan Tehran. Karaj, Tehran and surrounding faults are shown in Figure 1. As it is seen; the west part of the North Tehran fault passes through Karaj. So it is important to estimate the earthquake ground motion caused by this fault in the city.

North Tehran fault with the length of 110 km which is counted as a thrust fault (Tchalenko et al.<sup>1</sup>) and Berberian et al.<sup>2</sup>) is the target fault in this study. The devastating earthquakes of 855 to 856 (exact year is uncertain) and 1177 could have been caused by this fault (Berberian<sup>3</sup>).

Strong ground motion will be predicted in the site of Karaj Shah Abbasi Caravansary which is a historical building located in the down town and is one of the oldest structures in the city. This caravansary belongs to Safavid dynasty and built between 1688 to 1698 A.C. It is one of the hundreds caravansaries along the Silk Road. Caravansaries had been roadside inns where travelers could rest and recover from the day's journey. They supported the flow of commerce, information, and people across the network of trade routes.

Results of strong motion simulations in different distances will also be compared with an attenuation relation that has developed for Iran plateau and also one of the most popular attenuation relations that has developed for world. This comparison will carried out for two types of soil.



**Figure 1.** Karaj, Tehran and surrounding faults



**Figure 2.** Karaj Shah Abbasi Caravansary

## 2. FINITE FAULT MODELING WITH DYNAMIC CORNER FREQUENCY

One of the most useful methods to simulate ground motion for a large earthquake is based on the simulation of several small earthquakes as subevents that comprise a large fault-rupture event. This idea for the first time was introduced by Hartzell<sup>4)</sup>; when he used this method to model the El Centro displacement record for the 1940 Imperial Valley earthquake. In this method a large fault is divided into  $N$  subfaults and each subfault is considered as a small point source. The contributions of all point sources are summed in the observation point and large event is produced.

One of the simple solutions for this method was

proposed by Beresnev and Atkinson<sup>5)</sup>. In this solution target fault is divided to  $nl \times nw (=N)$  subfaults with unique dimensions. For each subfault ground motion is being produced by stochastic source point method with an  $\omega^2$  model. By considering the effects of path and site, the produced motions for all subfaults are summed in the observation point with a proper time delay to obtain the ground motion acceleration from the entire fault:

$$a(t) = \sum_{i=1}^{nl} \sum_{j=1}^{nw} a_{ij}(t + \Delta t_{ij}) \quad (1)$$

Where  $\Delta t_{ij}$  is relative delay time for the radiated wave from the  $ij$ th subfault to reach the observation point and  $a_{ij}$  is the subevent (motion) which

coincides with the  $ij$ th subfault.

Despite of all advantages of this approach, Motazedian and Atkinson<sup>6)</sup> showed that the received energy at the observation point is very sensitive to subfault sizes e.g. as the subfault sizes are increased the energy at low frequency is decreased and the energy at high frequencies is increased. They overcame this problem by introducing a “dynamic corner frequency“. In this model, the corner frequency is a function of time, and the rupture history controls the frequency content of the simulated time series of each subfault.

The rupture begins with a high corner frequency and progresses to lower corner frequencies as the ruptured area grows.

Stochastic finite fault modeling based on a dynamic corner frequency is adopted in this study so the success of the simulation is not dependent to the subfault size any more. The new model can also implement the concept of pulsing area because now it is generally accepted that the rise time of subfaults are much smaller than the duration of fault rupture. Thus, a realistic model of fault rupture should allow

for this behavior.

Table 1 Modeling parameters	
Fault orientation	Strike 305°; Dip 35°
Fault dimensions along strike and dip	46 by 26 km
Fault depth range	3 – 18 km
Moment magnitude	7.1
Subfault dimensions	2 by 2 km
Stress parameter	68 bars
Number of subfaults	299
Q (f)	$87f^{-1.147}$
Geometrical spreading	$1/R, R \leq 70$ km $1/70, 70 < R \leq 130$ km $\frac{1}{70} \sqrt{\frac{130}{R}}, R > 130$
Windowing function	Saragoni-Hart
Kappa factor (High-cut filter)	0.05
Pulsing area	50%
Crustal shear-wave velocity	3.5 km/sec
Rupture velocity	$0.8 \times$ shear wave velocity
Crustal density	$2.8 \text{ g/cm}^3$

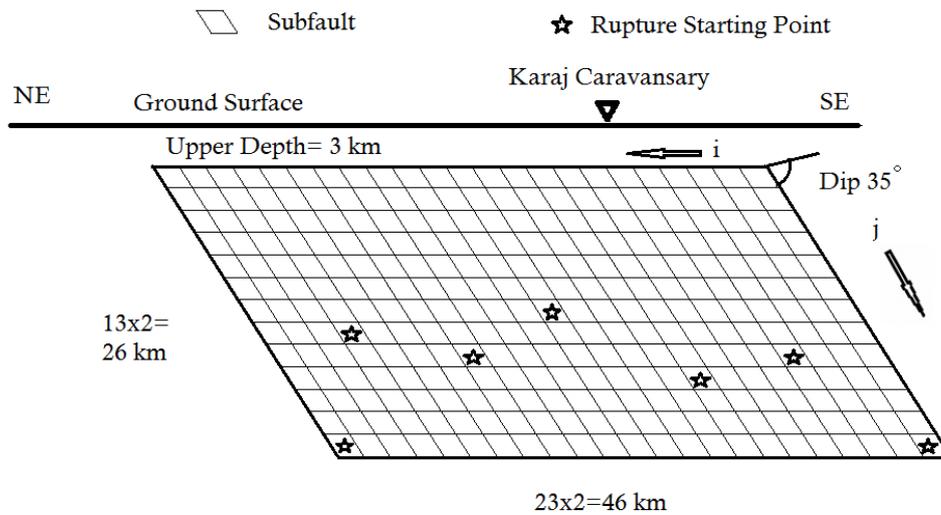


Figure 3. Geometry of the fault

### 3. ANALYSIS AND RESULTS

As it pointed earlier the target fault is North Tehran fault. The location of the fault is decided based on the map of major active faults of Iran, published by IIEES<sup>7)</sup>. The thrust dip of this fault is highly variable from 10 to 80 degrees towards north (Tchalenko et al.<sup>1)</sup>). In the west part dip is roughly estimated to be about 35° (Berberian et al.<sup>2)</sup>)

As it is seen in the Figure 1, North Tehran Fault is divided into 3 segments; A, B and C. These 3 segments are Karaj-Mahdasht, Kan and Lashgarak segments respectively. In this study earthquake

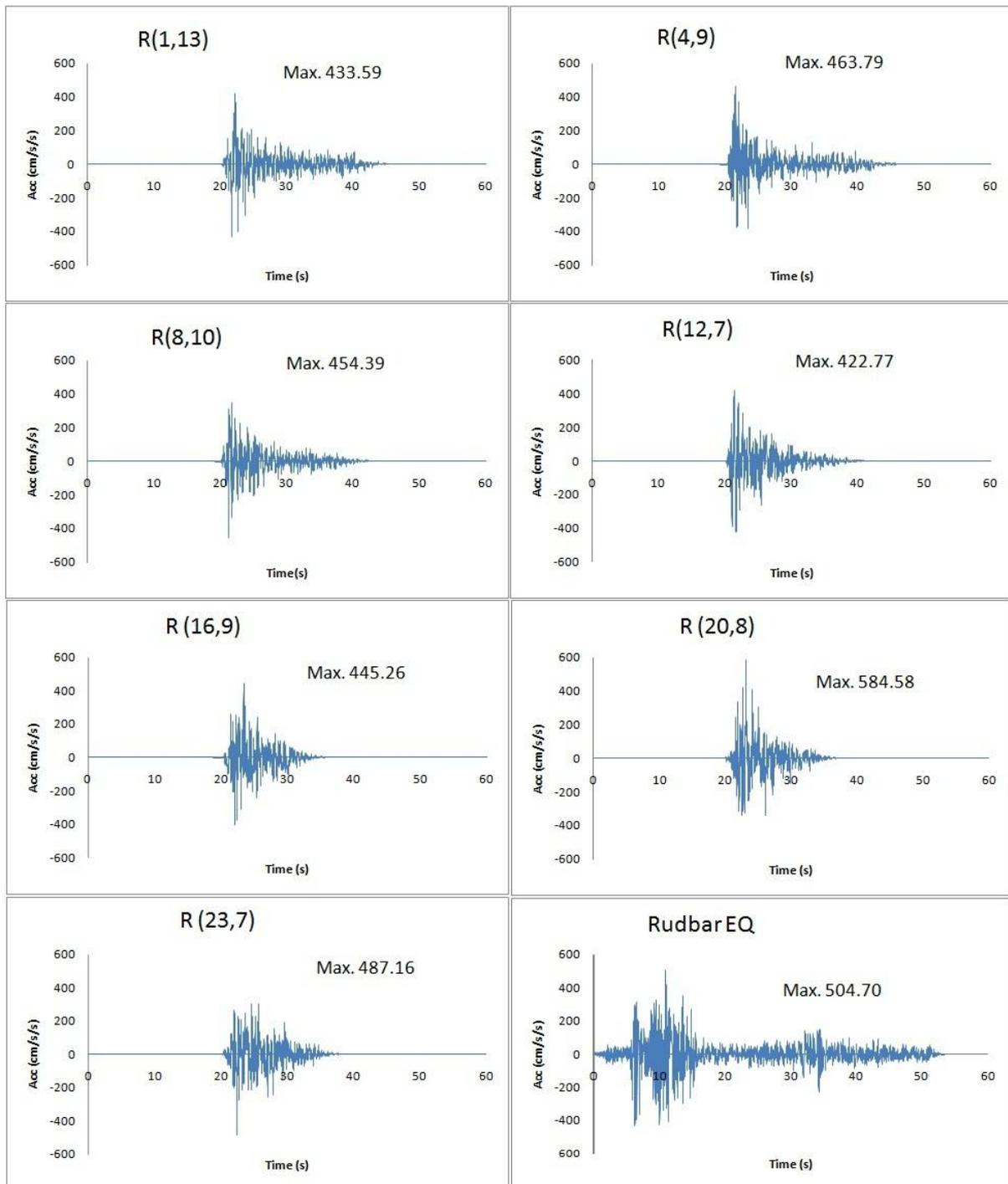
accelerograms are predicted for rupture of “A” segment which is closest to Karaj. The upper depth and lower depth are decided from recorded events of institute of geophysics, University of Tehran from 1998 to 2011. All the recorded events had the hypocenter between depths of 3 to 18 kilometers so the siesmogenic depth decided to be from 3 to 18 kilometers.

In finite fault method, modeling of the finite source requires the orientation and dimensions of the fault plane, the dimensions of subfaults and the location of the hypocenter. The parameters used in this study are listed in Table 1. Moment magnitude is

calculated from empirical relationships of Wells and Coppersmith<sup>8)</sup> for reverse faults by considering rupture area, Stress parameter, percentage of pulsing area, Q value and high cut filter are based on the work by Motazedian<sup>9)</sup> for earthquakes in northern Iran. We don't have information of slip distribution on the fault; therefore unity slip rate for all subfaults has been used.

In Figure 3, geometry of the fault and location of Karaj Caravansary are shown. Seven points are

assumed as rupture starting points and acceleration time histories for those points are drawn in Figure 4. The soil condition of Caravansary estimated to be type II of Iranian code of practice for seismic resistant design of buildings<sup>10)</sup> (standard 2800) site classes. The site amplification factors employed here are those of Boore and Joyner<sup>11)</sup> for various sites which are characterized by the average shear wave velocity.



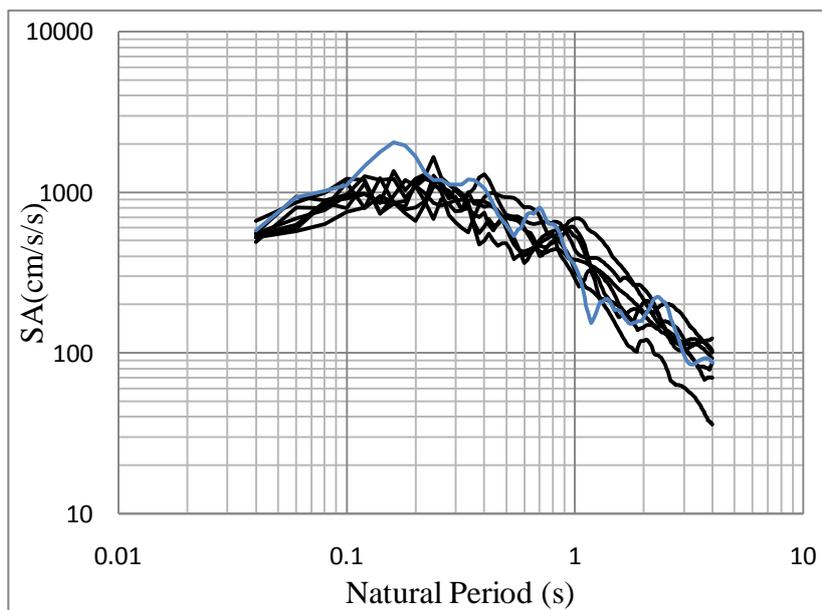
**Figure 4.** Predicted acceleration time histories for one horizontal direction for different rupture starting points and observed record of L component, Rudbar Earthquake (R (i, j) implies the location of rupture starting point in ijth subfault)

Acceleration time history of Rudbar earthquake (1990/06/20, Mw=7.4) is also shown in Figure 4. This earthquake was chosen for comparison because it was one of the devastating earthquakes that occurred in the last decades in Iran and its accelerogram is available. In this earthquake 40,000 to 50,000 people were killed and extensive damage and landslides observed in the Rasht-Qazvin-Zanjan area. The shown accelerogram is the L component of the record at Abbar station of BHRC ground motion stations. Average shear wave velocity of upper 30 meter in this station; is 621 m/sec as Sinaeian et al.<sup>12)</sup> (2007) report; therefore it is also characterized in type II of Iranian code of practice for seismic resistant design of buildings<sup>10)</sup> (standard 2800) site classes like the site of Karaj Caravansary. The seismogram recorded in Rudbar earthquake has hypocenter distance of 43 km and our simulations have hypocentral distances of 20 – 37 kilometers. As it can be seen in the figure, we have the peak

accelerations from 423 cm/s/s to 584 cm/s/s which are in the range of Rudbar earthquake (505 cm/s/s) but our simulations have shorter duration of ground motion.

We should point out here that the difference of the PGA for different cases is mostly because of the stochastic process of generating the wave. The point source wave of every subfault is produced by the stochastic method of Boore<sup>13)</sup>. In this method a random Gaussian noise in time domain is modified such as its spectra will be the parametric description of expected ground motion's spectra.

For further comparison, 5% damped of acceleration response spectra of estimated time series and observed record of Rudbar earthquake is also shown in Figure 5. The figure shows that response spectra of our simulations are very close to the response spectra of observed Rudbar earthquake in range of engineering interest.

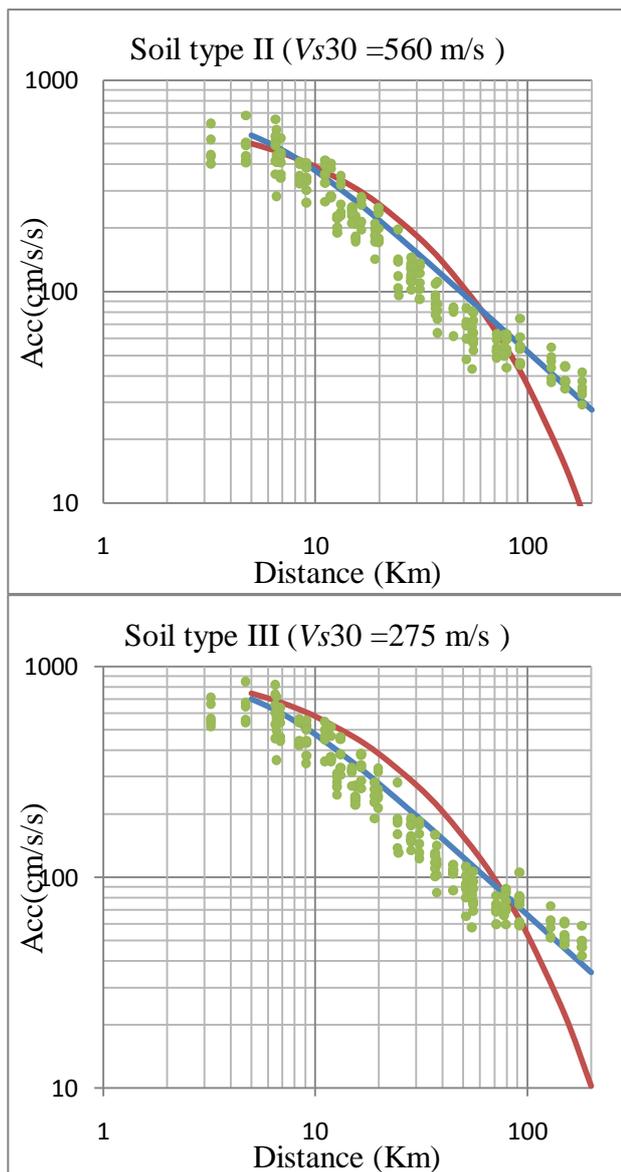


**Figure 5.** 5% damped of acceleration response spectra for estimated time series (black lines) and one of Rudbar earthquake (blue line)

Since in recent years no earthquake of target moment has happened around Karaj and thus no strong-motion recordings are available to compare the results of the simulation with actual data, we chose to draw a comparison with attenuation laws developed for Iranian plateau or similar regions. Attenuation relationships estimate ground motion as a function of magnitude and distance.

Using the stochastic finite-fault model of Motazedian and Atkinson<sup>6)</sup> with the model parameters listed in Table 1, we generated random horizontal components of motion in different distances for two types of soil conditions. Soil

conditions we considered here are soil type II and III of Iranian code of practice for seismic resistant design of buildings<sup>10)</sup> (standard 2800) with  $V_{S30} = 560$  m/s and  $V_{S30} = 275$  m/s respectively. ( $V_{S30}$  is the time-averaged shear-wave velocity in the top 30 m of the site profile) Site amplification curves versus frequency for these types of soil are derived from Boore and Joyner<sup>11)</sup> curves of NEHRP site classes by interpolation. A unity slip distribution is assumed and six random locations of the hypocenter on the fault plane are also considered. We simulate records for six values of equally spaced azimuths from zero to 360°, for each of the five hypocenters.



**Figure 6.** Maximum accelerations from simulations versus closest distance to the surface projection of the fault (dots) in comparison with two attenuation models; first: Campbell and Bozorgnia (blue line), second: Saffari (red line)

Figure 6 plots maximum acceleration (PGA) from simulations versus closest distance to the surface projection of the fault (commonly denoted as “Joyner-Boore distance”  $r_{jb}$ ) in comparison with the two empirical attenuation models. First attenuation model we chose here is well known model of Campbell and Bozorgnia<sup>14)</sup> which is developed for world earthquakes. Second one is model of Saffari<sup>15)</sup> which is newest model that has developed for Iranian plateau.

As can be seen in this figure, in distances from 5 to 30 kilometers results of our simulations agrees well with both of attenuation models. In distances between 30 to 70 kilometers our simulations show

lower values. Finally in distances more than 70 km they agree very well with Campbell and Bozorgnia model but show higher values compared with Saffari model. This difference which is more sensible in distances over 100 kilometers is mostly because of lack of recorded data in Iran that makes attenuation relations of this region unreliable in far distances (Saffari<sup>15)</sup>).

#### 4. CONCLUSIONS

Acceleration time series of strong ground motion are predicted for Karaj city in the site of Karaj Caravansary. Finite fault modeling with a dynamic corner frequency adopted for simulation. Target fault is North Tehran fault with the length of 110 km and the rupture of west part of it which is closest to Karaj, assumed for this simulation. For seven rupture starting points acceleration time series are predicted. Peak ground accelerations for those are vary from  $423 \text{ cm/s}^2$  to  $584 \text{ cm/s}^2$  which is in the range of Rudbar earthquake with the same soil characteristics and a bit of further hypocentral distance.

We also compared results of our simulations in different distances with attenuation relationships. We showed that PGAs of finite fault simulations agrees well with attenuation models.

In this study a unity distribution of slip for all subfaults considered for simulation. Further studies should be done by modeling asperities of the fault or by considering proper slip distribution over the fault. This is possible with the inversion analysis of middle sized earthquakes caused by rupture of the target fault. Doing this has been difficult for North Tehran fault because this fault has not been that active so far and we have less recorded data from this fault (Ashtari et al.<sup>16)</sup>).

#### REFERENCES

- 1) Tchalenko, J.S., Berberian, M., Iranmanesh, H., Bailly, M. and Arsovsky, M.: Tectonic framework of the Tehran region, *Geological Survey of Iran*, Rep. 29,: 7-46. 1974.
- 2) Berberian, M., Qorashi, M., Arzhangraves B., and Mohajer-Ashjai, A.: Recent tectonics, seismotectonics, and earthquake-fault hazard study of the Greater Tehran region (Contribution to the Seismotectonics of Iran, Part V), *Geological Survey of Iran*, Report.: 56, 316. 1985. (in Persian)
- 3) Berberian, M.: Natural hazards and the first earthquake catalog of Iran, Vol. 1: historical hazards in Iran prior 1900, I.I.E.E.S. Report. 1994.
- 4) Hartzell, S.: Earthquake aftershocks as Green's functions, *Geophysical Research letters*. 5, 1-14. 1978.
- 5) Beresnev, I. A., and Atkinson, G. M.: Modeling finite-fault radiation from the  $\omega^n$  spectrum, *Bulletin of*

- the *Seismological Society of America*, 87, 67–84.1997.
- 6) Motazedian, D., and Atkinson, G. M.: Stochastic Finite-Fault Modeling Based on a Dynamic Corner Frequency, *Bulletin of the Seismological Society of America*, 995–1010. 2005.
  - 7) Hessami, K., Jamali, F. and Tabbasi, H.: Major Active Faults of Iran, International Institute of Earthquake Engineering and Seismology. 2003.
  - 8) Wells, D. L. and Coppersmith, K. J.: New empirical relationships among magnitude, rupture length, rupture width, rupture area and surface displacement *Bulletin of the Seismological Society of America*, Vol. 84:974–1002. 1994.
  - 9) Motazedian, D.: Region-specific key seismic parameters for earthquakes in Northern Iran *Bulletin of the Seismological Society of America*, Vol. 96:1383–1395. 2006.
  - 10) Building and Housing Research Center (BHRC): Iranian Code of Practice for Seismic Resistant Design of Buildings (standard 2800)”, Building and Housing Research Center (BHRC), PN S 465. 2005
  - 11) Boore, D. M. and Joyner, W. B.,: Site Amplification for Generic Rock Sites, *Bulletin of the Seismological Society of America*, 87, 327 – 341. 1997.
  - 12) Sinaeian, F., Zare, M. Mirzaei Alavijeh, H., and Farzanegan, E.: Study of site amplification and soil characterizing of accelerometric stations. *The 5th International Conference on Seismology and Earthquake Engineering (SEE5)*, International Institute of Earthquake Engineering and Seismology (IEES), Tehran, Iran. 2007. (In Persian)
  - 13) Boore, D. M.: Stochastic simulation of high-frequency ground motions based on seismological models of the radiated spectra. *Bulletin of the Seismological Society of America*, 73, 1865–1894. 1983.
  - 14) Campbell, K. W. and Bozorgnia, Y.: NGA Ground motion model for the geometric mean horizontal component of PGA, PGV, PGD and 5% damped linear elastic response spectra for periods ranging from 0.01 to 10 s. *Earthquake Spectra*. Vol. 24:1. P. 139-171. 2008.
  - 15) Saffari, H.: Probabilistic Seismic Hazard Analysis and Site-Specific Design Spectra of Iran. *Doctoral thesis*. Kobe University, Jan, 2011.
  - 16) Ashtari, M.; Hatzfeld, D.; Kamalian, N.: Microseismicity in the region of Tehran” *Tectonophysics*, No. 395:193– 208. 2005.