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# The Generation of Earthquake PGA Using Stochastic Finite Fault Method in Alborz Region

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**Abstract**

Time-history analysis is defined as a kind of dynamic analysis increasingly used in design of structures and evaluation of existing ones. One of the important issues in the Time-history analysis is selecting earthquake records. In this case, seismic design provisions states that time histories shall have similar source mechanisms, geological and seismological features with region under study. Alborz is one of the highly seismic regions of Iran which records of large events are not sufficiently available. For this reason, the main objective of this research is to modeling strong motion records and comparing those with observed records. For modeling strong motion at a particular site three main elements: regional earthquake source, propagation path effects and local site conditions should consider. In this study stochastic finite fault approach for generation earthquake accelerographs was used. The use of a finite fault model is particularly important in improving the reliability of estimates for large-magnitude events at close distances. Finally after comparing the results, the generated records are found to be consistent with observed records in Alborz region.

**Keywords:** Dynamic analysis, Alborz region, Accelerographs, Stochastic finite fault.

## I. Introduction

In earthquake design the attention to balance between ground-motion potential that result in damage and structure capability against this damage (capacity) is crucial. Engineering structures capacity could obtain through experimental studies, analytical models and field observations of earthquakes data. But seismic demand obtains by recorded accelerographs of different earthquakes. So the most important discussion on structure time history analysis and also seismic application is earthquake accelerographs selecting to apply for mentioned structure to design. Iranian seismic code [1] reveals that accelerographs which use to determine earth movement should show earth real movement on building area and include following features:

1. Accelerographs belong earthquakes must meet design earthquake condition and consider amplitude, fault distance and seismic source act effects.
2. Accelerographs built areas should be similar to building area in terms geology, tectonic, seismology and especially soil layers characteristics.
3. Earth severe movement duration in accelerographs to be 10s or three times of structure's main period, for structure analysis.

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Then as mentioned before, to analyze time history need earthquake records in each area on the base of geology and seismology properties. In low seismic regions and areas that have not past earthquakes information such earthquake record number access is not available. In Iran also spite of high seismic regions there is not enough earthquake accelerographs data. In the other hand, access to such earthquakes record number is not easy so should seek situated methods. Iranian seismic code [1] persists that in cases without recorded accelerographs with mentioned characteristics; it can be used artificial simulated accelerographs. Regarding to introduce discussions it needs to produce artificial accelerographs in regions that there is not enough earthquake data. In this study by using stochastic finite fault method earthquake accelerographs produced in Alborz region. It was tried to use Alborz area seismic parameters to produce earthquake records to be similar mentioned area in terms of geology, tectonic, seismology and especially soil layers.

## 2. Backgrounds

Many researchers to now have used stochastic earthquake produce method to study different seismology and earthquake engineering issues. Margaris and Boore [2] assessed stress drop parameter by using point source method. They first calculated this model on eight earthquakes response spectrum in Greek with magnitude 5.8- 6.9, and finally calculated stress drop parameter by using area parameters that its mean was 56 bars. Atkinson and Boore [3] introduced an attenuation relationship by using earthquake stochastic method by producing thousands artificial data in east of Northern America. In general such decreasing equations should consider area earthquake source characteristics, dispersion direction effects and built response properties [4]. Attenuation relationship is a mathematic equation between earthquake characteristic and other earthquake parameters that indicates seismic waves decreasing through source to site distance. Obtained results are according to this area earthquake recorded data so that predicted rate and residuals in all frequencies is close to zero. Moghaddam et al. [5] used this procedure to calculate stress drop parameter related to 52 shallow earthquakes. But in conducted study by them in addition to point source method, finite fault method was used for modeling. Data used in their study included 52 shallow earthquakes in magnitude of 4.4-7.6 in order to considering. To decrease site effects simulated 54 acceleration spectrum of these events simulated in rock and compared with their observed values. Obtained result indicates that assessed stress drop parameter on the based of finite fault method is smaller than calculated stress drop parameter on point source method.

Nicknam et al. [6] by study of seismology parameters in east-south of Iran and Bam earthquake produced this earthquake by using stochastic method and introduced attenuation equation for Fourier spectrum range in this region. Zafarani et al. [7] simulated eight main Iran earthquakes by using Beresnev and Atkinson [8] suggested method and corrected obtained results by recorded data and then by using information of three faults Mosha, North Tehran and Ray, modeled huge Tehran earthquakes. In conducted study maximum value of horizontal component of time histories assessed up to 0.7g in west–north of Tehran.

Yazdani and Abdi [9] produced many earthquake artificial catalogs by using Monte Carlo method and calculated designed earthquake with 475 years return period by using seismic hazard analysis then using deaggregation method they obtained design artificial records in Tehran for determined magnitude and distances.

## 3. Alborz region

Alborz region including Iran north areas ends to Khazar Sea from north and central Iran plateau from south. Alborz studies of historical events indicate that this part of Iran such as other parts faced destructive earthquakes during history and have destroyed many cities and villages. Seismic studies and its effect on structures and Alborz morphology has interested by researchers and investigators since half of century and these studies results have published. Ambraseys [10, 11] has looked records collecting related to historical earthquakes to forth century B. C. in this area. In conducted study has referred to destructive earthquakes. Ambraseys has considered three main areas in Alborz earthquake, as in west has occurred Anzali and Rasht destructive earthquakes. Middle part including Amol, Babol and Sari earthquakes and in east part Behshahr, Gorgan destructive earthquakes have verified. Some researchers have measured Alborz earthquakes hypocenter in 10 km less deeper than 33 km border but in Folk et al. [12] study it seems that in north Alborz earthquakes focal depth is 16 km. Active Alborz faults are Rudbar, Lahijan, Talesh, North Qazvin, Khazar, North Alborz, Mosha, North Tehran, Ray, Taleghan, Eshtehard, Kahrizak faults that are shown in Figure 1. In Rudbar earthquake in 1990 at least 80 km surface fault through three discrete faults in line left turning riddle and small reverse fault item on Rudbar earthquake fault surface occurred that has been shown in Figure 1 [13].

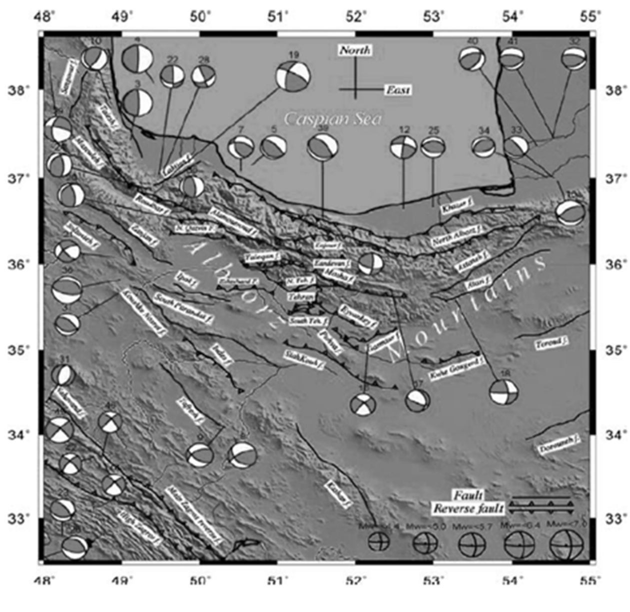


Figure 1 – Active faults and Harvard CMT solution of the Alborz region [13].

Alborz region has experienced destructive earthquakes up to now. The most important earthquakes in this area in recent years refer to 20 June 1990 Rudbar earthquake in Mw=7.4, 22 June 2002 Avaj earthquake in Mw=6.5 and 28 May 2004 Kojor earthquake in Mw=6.3 that these events had many damages. Figure 2 shows Alborz instrumental earthquake catalog which recorded in 20 century.

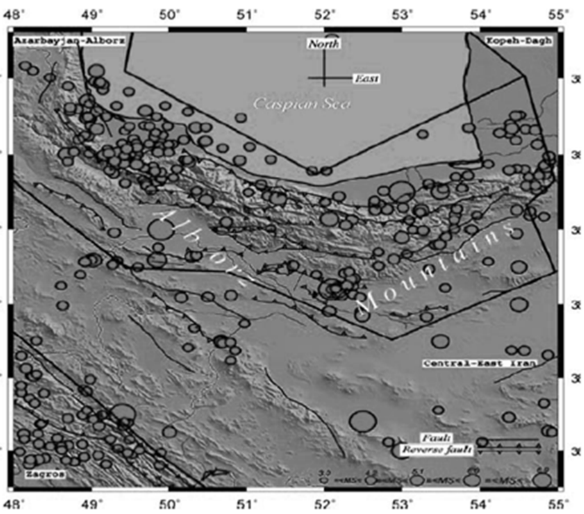


Figure 2 – Instrumental seismicity of the Alborz and surroundings after 1900 [13].

## 4. Earthquake producing

An earthquake characteristic is affected by its fault geology and dynamic characteristics. Geology characteristics include size, distance, focal depth, dip and azimuth angle and slip distribution of fault during earthquake. Dynamic characteristics also include tensions on fault, surrounding fault rocks, physical properties and fault strength. Stochastic model is a simple and most using method to produce earthquake that models earthquake rang by using released seismic energy and wave distribution on one unit, source to site distance, fault dimensions and many other parameters.

Stochastic generation method used in this study is on the basis of Hanks and McGuire [14] study that combined earthquake spectrum range seismology models and indicated that high frequency movements are random. Assuming far area accelerations are limited in a semi–elastic environment earthquake time, Gussian white noise and source spectrum explains by individual corner frequency model this corner frequency on the basis of Brune model [15, 16] depends on earthquake size. The most basic element of stochastic model is earthquake spectrum that these models simplify shows earthquake physic process and waves distribution. In this model earthquake spectrum classifies in separate elements such as seismic source, path, site and movement type and defines as follow:

$$Y(M_0,R,f)=E(M_0,f)P(R,f)G(f)I(f) \quad (1)$$

That in this equation E(M.,f) is a coefficient that reflects seismic source effects, P(R,F) indicates path effects and G(f) is upper crust attenuation factor and I(f) is a coefficient that shows site effects in modeled earthquake .

Source form and spectrum range should consider as a function of earthquake size that is the most important part of modeling. ω–square is the most common model to serve seismic source affect that first introduced by Aki [17]. $\omega^2$ model in equation (2) shows shear waves transferring in seismic source:

$$E(M_0,f)=\frac{CM_0}{(1+(f/f_c)^2)} \quad (2)$$

Constant C in equation (2) calculates as follow:

$$C=R_{\phi\theta}VF/(4\pi\rho_s\beta_s^3R_0) \quad (3)$$

That in this equation $R_{\Phi\theta}$ is the radiation pattern or wave radiation factor (0.55 for shear waves), $V$ is the partition of total shear wave energy into horizontal components (0.707), $F$ is the effect of the free surface factor (in often practical use is 2), $\rho_s$ and $\beta_s$ are the density and shear-wave velocity in the vicinity of the source, respectively and $R_0$ is a reference distance, usually set equal to 1 km.

One of the important factors to model earthquake is path effect. For most practical uses path effects serve with simple function that show geology radiation, wave's radiation and shearing effects. Waves radiation path effect serves in two geometric attenuation factor G (R) and anelastic whole path attenuation factor $A_n$ (f):

$$P(R,f)=G(R)A_n(f) \quad (4)$$

Geometrical spreading function G(R) is given by a piecewise continuous series of straight lines. In addition to that, another parameter to show waves radiation path is anelastic whole path attenuation factor which includes all the losses which have not been accounted for by the geometrical attenuation factor which defines by equation (5):

$$A_n(f)=e^{-\pi fR/Q\beta} \quad (5)$$

That in this equation f is frequency of the wave, $R$ is the length of the wave travel path, β shear waves velocity. Q is the wave transmission quality factor that defines according to equation (6):

$$Q=Q_0(f^n/f_0) \quad (6)$$

Where $f_0$ is unit frequency in 1 Hz and $Q_0$, n are the regional dependent factor and exponent respectively factors. Site effect could classify into two parts D(f) attenuation effect and A(f) amplification:

$$G(f) = A(f)D(f) \quad (7)$$

To serve upper layers attenuation effect uses a equation similar to An(f) equation but R/Qβ ratio used in equation (5) centered on a single parameter κ. Shear waves radiated towards up become sever when enter to a layer with lower velocity. Changes in passing shear waves domain from two environments (from A to B) are according to energy stability principle. Domain increasing coefficient defines by equation (8) [18]:

$$A(f) = \sqrt{\frac{\rho_A \nu_A}{\rho_B \nu_B}} \quad (8)$$

Where $\rho_A$ and $\rho_B$ are density and $\nu_A$, $\nu_B$ are shear wave velocity in two environments. Finally after study of mentioned factors accelerographs will produce. Simple steps of accelerographs producing will be as in first step white noise (Gussian or uniform) produces for earth movement duration then in second step this noise separates. In third step separated noise transmits to frequency domain and in fourth step this spectrum normalizes by using mean squares method. In fifth step normalized spectrum multiplies to earth movement parameter and finally obtained results again transmit to time domain and produces mentioned accelerographs.

Finite fault method is known as a suitable tool to produce huge earthquakes. In finite fault method, main fault separates to subfaults in rectangular form and calculates each sub-fault effect on field by using point source method and all of them will sum. In finite fault method assumes that fault rupture starts in center and widesradially. Each element when moves that rupture arrives its center. Such elements participation effect sum to each other by a delay in site. Finally, the produced accelerographs by each subfault are added to each other by considering time delay as shown in equation (8):

$$a(t) = \sum_{i=1}^{nw} \sum_{j=1}^{nl} a_{ij}(t + \Delta t_{ij}) \quad (9)$$

Where nl ,nw are the number of sub-faults in length and width of fault surface .

## 5. The used parameters

As mentioned before, to produce earthquake by using limited fault method needs information on source, path and site effects is needed. Needed parameters are magnitude, distance, fault direction (in length and depth), above fault edge depth, statistic stress drop and needed parameters to assess waves transitions quality and anelastic attenuation.

Also considering area faults position and separating them to subfaults and knowledge about these faults tectonic characteristics are very important. As mentioned before in this study $\omega^2$ model was used to serve seismic source effect. Regarding to Brune source model [15, 16] three parameters seismic place, stress drop and shear wave acceleration near to source is needed.

Shear wave velocity is 3.5 to 3.7 km/s. Next parameter that has main effect for source model and spectrum is seismic moment. The third parameter that is stress drop should place in studying area on the basis of conducted researches. Zafarani et al [7] to produce earthquake in Tehran considered stress drop in 50 bars. Motazedian [19] assessed this parameter in Alborz by using point source and finite source method. In their study stress drop for Alborz area was 125 bars by using random point source method and by using finite fault method was 68 bars.

After fault rupture as seismic source when earthquake, radiated seismic waves depend on different parameters during movement towards site. Geometric attenuation factor studies by a three line model. In this study shear waves radiation to 70 km distance as circularly is I/R. In 70 to 150 km distance reflects as $R^{0.2}$ [19] and in up to 150 km earth surface movements are affected by different reflections body waves on earth surface that such waves attenuate in $R^{-0.6}$ in a cylindrical distribution. Next effective parameter is anelastic attenuation factor in whole path that depends on wave frequency, wave's movement path length, shear waves velocity and waves transmitting quality factor. This factor shows waves radiation quality in studying area and has an inverse relation seismic wave's anelastic attenuation. Regarding to structural seismic characteristics which is different in region to region. Usually waves transmitting quality factor behavior is as U form but in higher frequencies than is assess as linear. Motazedian [19] suggested $Q=87f^{1.46}$ for north Iran. The most effective parameter to produce earthquake is using *k* parameter random method that in this study is 0.05 [19]. Shear wave velocity and density has considered 3.5 ton /$m^3$ and 2.8 km/s. But another important factor to study site effects is folding that in this study has used Boor and Joyner suggested factors [18]. To produce earthquake need studying faults rupture length and width is needed. Also to obtain rupture length and width used Wells and Coppersmith [20] equations.

## 6. Conclusions and Discussion

In this study after obtaining different seismic parameters, it is necessary to verify simulated accelerographs with Alborz observed records. Because of finite fault method ability to produce huge earthquakes so produced earthquakes compared to three huge earthquakes in this area such as 1990 earthquake in Rudbar Mw=7.4, 2002 Changore and Avaj Mw=6.5 and 2004 Kojor Mw=6.3, these earthquakes information and also data acceleration comparing with produced earthquakes has shown in Table 1.

Table 1 – Characteristics of selected records and comparison between observed and generated records (PGA(sim)) for PGA in Alborz region. ($cm/sec^2$)

| Station | Record ID | Lon (EQ) | Lat (EQ) | Date | Time | Lon (St) | Lat (St) | FD | PGA(Sim) | Mw | PGA |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Qazvin | 1353/01 | 50.00 | 36.26 | 6/20/1990 | 21:00:31 | 49.41 | 36.96 | 18 | **155.03** | 7.4 | 161.0 |
| Abhar | 1354 | 49.22 | 36.09 | 6/20/1990 | 21:00:31 | 49.35 | 36.99 | 18 | **191.67** | 7.4 | 180.8 |
| Rudsar | 1355 | 50.30 | 37.13 | 6/20/1990 | 21:00:31 | 49.35 | 36.99 | 18 | **104.42** | 7.4 | 97.50 |
| Lahijan | 1357/01 | 50.03 | 37.21 | 6/20/1990 | 21:00:31 | 49.35 | 36.99 | 18 | **110.81** | 7.4 | 148.8 |
| Tonkabon | 1359 | 50.88 | 36.808 | 6/20/1990 | 21:00:31 | 49.41 | 36.96 | 18 | **86.47** | 7.4 | 106.3 |
| Abbar | 1362/01 | 48.95 | 36.925 | 6/20/1990 | 21:00:31 | 49.41 | 36.96 | 18 | **491.65** | 7.4 | 591.8 |
| Zanjan | 1364 | 48.50 | 36.66 | 6/20/1990 | 21:00:31 | 49.41 | 36.96 | 18 | **64.90** | 7.4 | 85.70 |
| Eshtehard | 1372 | 50.37 | 35.72 | 6/20/1990 | 21:00:31 | 49.41 | 36.96 | 18 | **76.22** | 7.4 | 75.70 |
| Abegarm | 2748/01 | 49.28 | 35.756 | 6/22/2002 | 2:58:28 | 49.02 | 35.71 | 15 | **122.97** | 6.5 | 131.0 |
| Avaj | 2749/01 | 49.22 | 35.58 | 6/22/2002 | 2:58:28 | 49.02 | 35.71 | 15 | **469.48** | 6.5 | 473.3 |
| Kabodar Ahang | 2754/01 | 48.72 | 35.205 | 6/22/2002 | 2:58:28 | 49.02 | 35.71 | 15 | **130.46** | 6.5 | 117.7 |
| Razan | 2756/01 | 49.03 | 35.393 | 6/22/2002 | 2:58:28 | 49.02 | 35.71 | 15 | **196.28** | 6.5 | 196.9 |
| Abhar | 2763 | 49.22 | 36.15 | 6/22/2002 | 2:58:28 | 49.02 | 35.71 | 15 | **54.50** | 6.5 | 50.30 |
| Darsjin | 2769/02 | 49.23 | 36.023 | 6/22/2002 | 2:58:28 | 49.02 | 35.71 | 15 | **69.99** | 6.5 | 65.00 |
| Ghahvard | 2778 | 48.0۶ | 35.466 | 6/22/2002 | 2:58:28 | 49.02 | 35.71 | 15 | **55.43** | 6.5 | 67.90 |
| Shirin soo | 2781 | 48.45 | 35.487 | 6/22/2002 | 2:58:28 | 49.02 | 35.71 | 15 | **132.28** | 6.5 | 148.2 |
| Nowshahr | 3368/01 | 51.49 | 36.654 | 5/28/2004 | 12:38:48 | 51.56 | 36.3 | 22 | **76.91** | 6.3 | 87.50 |
| Noor | 3369/01 | 52.01 | 36.574 | 5/28/2004 | 12:38:48 | 51.56 | 36.3 | 22 | **53.58** | 6.3 | 54.90 |
| Rudsar | 3373 | 50.28 | 37.141 | 5/28/2004 | 12:38:48 | 51.56 | 36.3 | 22 | **60.01** | 6.3 | 52.10 |
| Qazvin1 | 3423 | 50.00 | 36.26 | 5/28/2004 | 12:38:48 | 51.56 | 36.3 | 22 | **55.38** | 6.3 | 53.80 |
| Razjerd | 3444 | 50.1۸ | 36.348 | 5/28/2004 | 12:38:48 | 51.56 | 36.3 | 22 | **50.33** | 6.3 | 53.40 |
| Astaneh | 3446 | 49.9۴ | 37.264 | 5/28/2004 | 12:38:48 | 51.56 | 36.3 | 22 | **51.89** | 6.3 | 53.20 |

Figure 3 shows the comparing between simulated PGA by finite fault method and observed PGA. But addition to earth maximum acceleration, spectrum acceleration parameter is another effective parameter to design structures so comparison between observed and generated records for spectral acceleration (Sa) in Alborz has been shown in Figure 4. It should be noted that the geometric means of the ground motion records for each horizontal component are used.

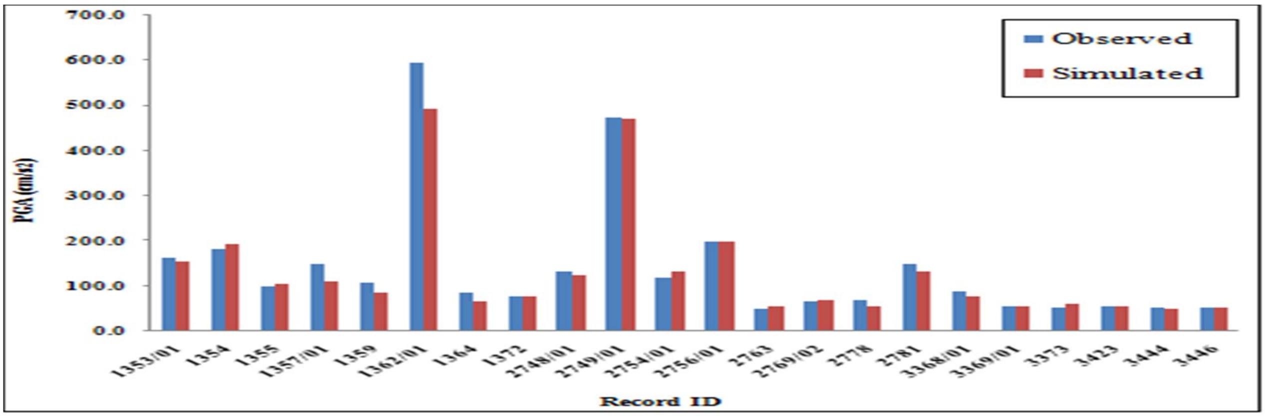


Figure 3 – Comparing Alborz observed records and generated earthquakes in this study.

Obtained results show produced events have good consistency to recorded data. Little difference among obtained results and current data indicates precise selecting effective parameters and also this method suitability to produce earthquake in this area.

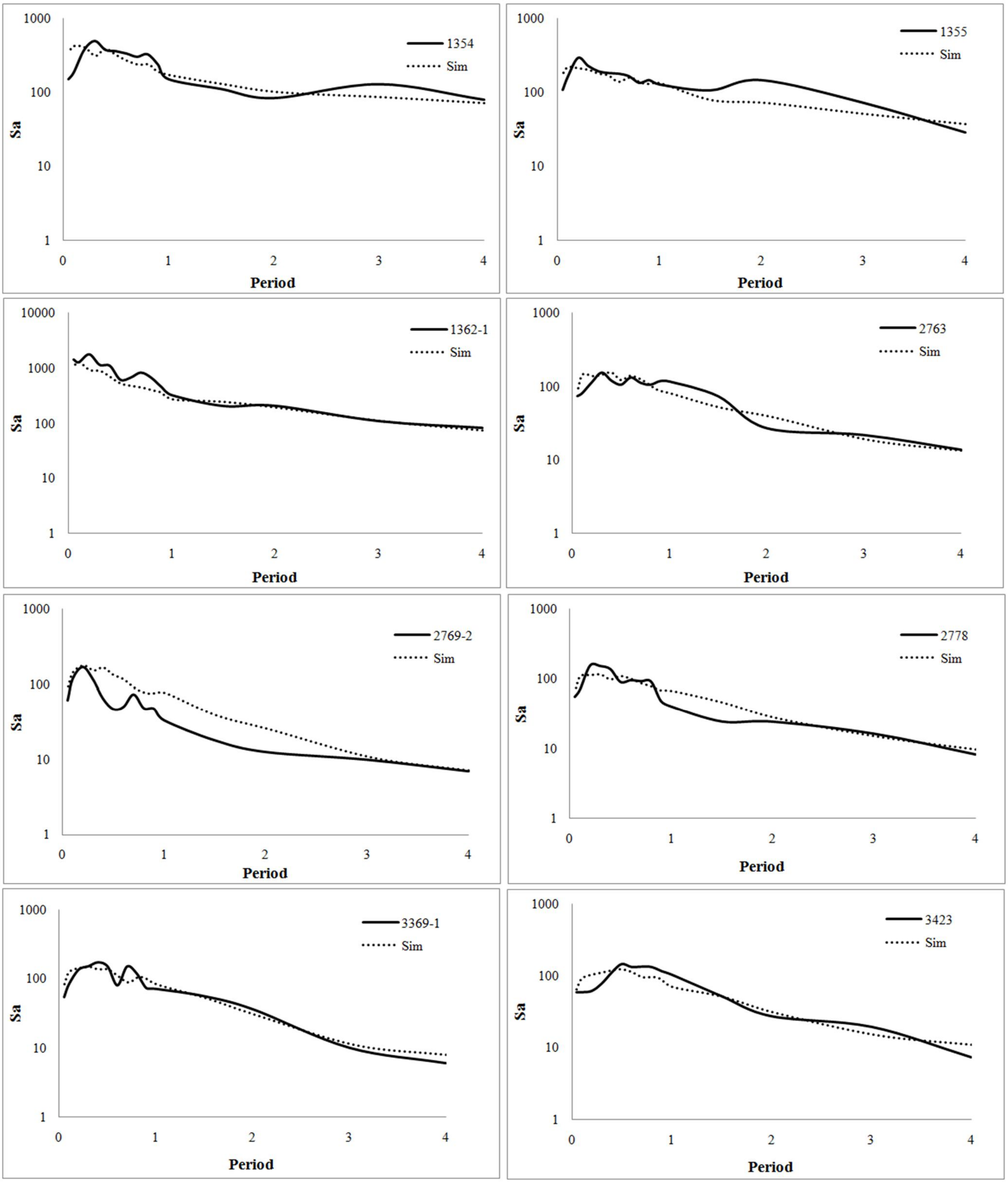


Figure 4 – Comparison between observed and generated records for SA in Alborz

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