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# Modelling of Synthetic Accelerograms for Locations in Kosovo

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**Abstract:** Strong ground shaking causes severe damages to man-made facilities and sometimes induce loss of human lives. Studies of the characteristics of observed accelerograms from earthquake events upgrade one's capability in seismic hazard mitigation. The review of the seismic activity affecting the territory of Kosovo, points out that the region should be considered as having high seismic hazard potential. In order to be able to assess the seismic hazard, it is necessary to integrate data from various fields such as seismology, geology, tectonics, geophysics etc. The number of real earthquake histories registered in the territory of Kosovo is very limited, because the first seismological stations were installed, very recently. This is especially a problem when it comes to dynamic structural analysis. Seismic ground motions of high-frequency are generally required as input for non-linear dynamic structural analysis by engineers, especially for those who are engaged in performance-based seismic design. Simulating earthquake ground motions by models that correctly describe the intensity and frequency content variation with time will allow more accurate prediction of structural performance. The finite-fault model method was used for simulation of strong ground motions for several locations in Kosova.

***Keywords:*** *simulation, finite-fault method, strong earthquake ground motion,*

## Introduction

Strong ground shaking causes severe damages to man-made facilities and unfortunately, sometimes induce loss of human lives. Studies of the characteristics of observed accelerograms from earthquake events upgrade one's capability in seismic hazard mitigation. To achieve satisfactory assessment of the seismic hazard it is important to have real time histories of the earthquakes that have happened in the considered region, since they are the source of information how the local soil structure influences and modifies the ground shaking.

The review of the seismic activity affecting the territory of Kosovo throughout the time, points out that the region should be considered as having high seismic hazard potential. Having in mind that in the last two decades, the region has undergone very fast urbanization characterized with extensive infrastructure development and building modern high rise structures with different use: residential, administrative, commercial and buildings belonging to essential facilities such are schools and hospitals, it is necessary to be aware of the seismic hazard to which the built environment can be exposed and all possible consequences of such event. In order to be able to assess the seismic hazard, it is necessary to integrate data from various fields such as seismology, geology, tectonics, geophysics etc.

The number of real earthquake histories registered in the territory of Kosovo is very limited, because the first seismological stations were installed, very recently (2008). Even in the countries were seismological networks exist for decades, number of different recordings that can be used in various analysis is very limited. This is especially a problem when it comes to dynamic structural analysis. Seismic ground motions of high-frequency (greater than 1 Hz) are generally required as input for non-linear dynamic structural analysis by engineers, especially for those who are engaged in performance-based seismic design. At the same time these time histories are of significant importance for seismologists as they provide data basic for the understanding of source processes. Ground motion at a particular site due to earthquakes is influenced by source, travel path and local soil conditions. The first relates to the size and source mechanism of the earthquake. The second describes the path effect

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of the earth as waves travel at some depth from the source to site. The third describes the effects of upper hundred meters of rock and soil and the topography of the site.

Most real-world random phenomena are transient in nature; such is the case for most natural loadings on structures. For example, the earthquake ground motions consist of seismic waves of different periods arriving at different times. Both their intensity and frequency content are changing with time. In particular, the long period pulses observed in many near-fault earthquake records have been shown to cause serious structural damage. Simulating earthquake ground motions by models that correctly describe the intensity and frequency content variation with time will allow more accurate prediction of structural performance.

Generally speaking, structural responses are functions of the entire ground excitation time history. Scalar intensity measures such as spectral acceleration or displacement do not reflect satisfactorily the effects of near source and those due to higher modes and other important structural response behaviours caused by the ground motions, thus cannot adequately represent the earthquake demand on structures. For performance evaluation of complex structural systems, time history analysis has played a more and more important role. For time history analysis, simulation of earthquake ground motions is essential.

**Generation of synthetic ground motion time histories**

The spectral analysis of random processes traditionally relies on the Fourier decomposition of the processes, i.e. representing the processes by sine and cosine waves with fixed frequency and amplitude extending without bounds over time and space. It is inherently difficult when applied to non-stationary processes whose duration is short and amplitude and frequency contents change with time. All currently available methods of spectral analysis of non-stationary processes such as double frequency spectrum, instantaneous spectrum, physical spectrum, wavelet spectrum have some drawbacks.

Ground motion model has been introduced that characterizes strong ground motions as stochastic in time, with a Fourier amplitude spectrum specified by a fundamentally simple and deterministic seismological model of the source, path, and site. An essential and significant aspect of the model is that, while being extremely simple, it also provides estimates of strong ground motions with remarkable accuracy. Additional, but important, side benefits arising from the model's simplicity are the natural separation of source, path, and site effects and the accompanying computational efficiency.

The stochastic ground motion model, in which the energy is distributed randomly over the duration of the source, has proven remarkably effective in correlating with a wide range of ground motion observations. The ground motion model employed here uses an ω-square Brune source model with a single corner frequency and a constant stress drop.

The use of stochastic simulated ground motions can be very useful to establish possible earthquake scenarios, for seismic hazard analysis purposes of regions where there are few earthquake strong motion records available. However, in face of our sensitivity analysis results, we believe that it should be done carefully, because of the influence of parameter variability on simulated earthquake results.

**Concept of Analysis**

The territory of Kosova is seismic prone, and a number of active faults and seismic sources (Figure1) have been recognized that can pose a potential hazard to built environment and population. The most important active faults that can generate significantly strong earthquakes were defined (Table 1).

The general idea was to simulate earthquakes from several most significant fault structures in Kosova with magnitudes that correspond to maximum expected earthquake and obtain strong ground motion time history at each of the locations of the stations. In this way it is possible to follow how the distance from the fault (Table 1) influences the time history parameters as well as the influence of the characteristics of the fault itself (Table 2).

Macro-source parameters characterizing the whole source area, i.e. global source parameters such as fault length, fault width, rupture area, and average slip on the fault plane are estimated; secondly, slip distributions characterizing heterogeneity or roughness on the fault plane, i.e. local source parameters are reproduced by the hybrid slip model; finally, the finite fault source model, which is developed based on the global and local source parameters is combined with the stochastic method.

**Table 1.** Characteristics of the Considered Active Faults

| Fault ID Number | Length (km) | Depth (km) | Magnitude | | Distance (km) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | observed | Expected | PEJA | ZATK | PRZK | SMRK | GMRK | GJIK |
| **1** | 35 | 15 | 6.0 | 6.1 | 30 | 50 | 85 | 45 | 78 | 110 |
| **2** | 50 | 15 | 6.0 | 6.1 | 13 | 38 | 71 | 78 | 98 | 123 |
| **3** | 45 | 15 | 5.3 | 6.1 | 49 | 36 | 33 | 95 | 93 | 108 |
| **6** | 50 | 15 | 6.0 | 6.1 | 79 | 36 | 5 | 94 | 78 | 81 |
| **7** | 30 | 15 | 6.1 | 6.5 | 88 | 79 | 104 | 13 | 44 | 82 |
| **12** | 55 | 15 | 6.1 | 6.5 | 115 | 91 | 77 | 98 | 55 | 21 |
| **15** | 45 | 15 | 5.1 | 5.5 | 122 | 74 | 49 | 104 | 69 | 47 |

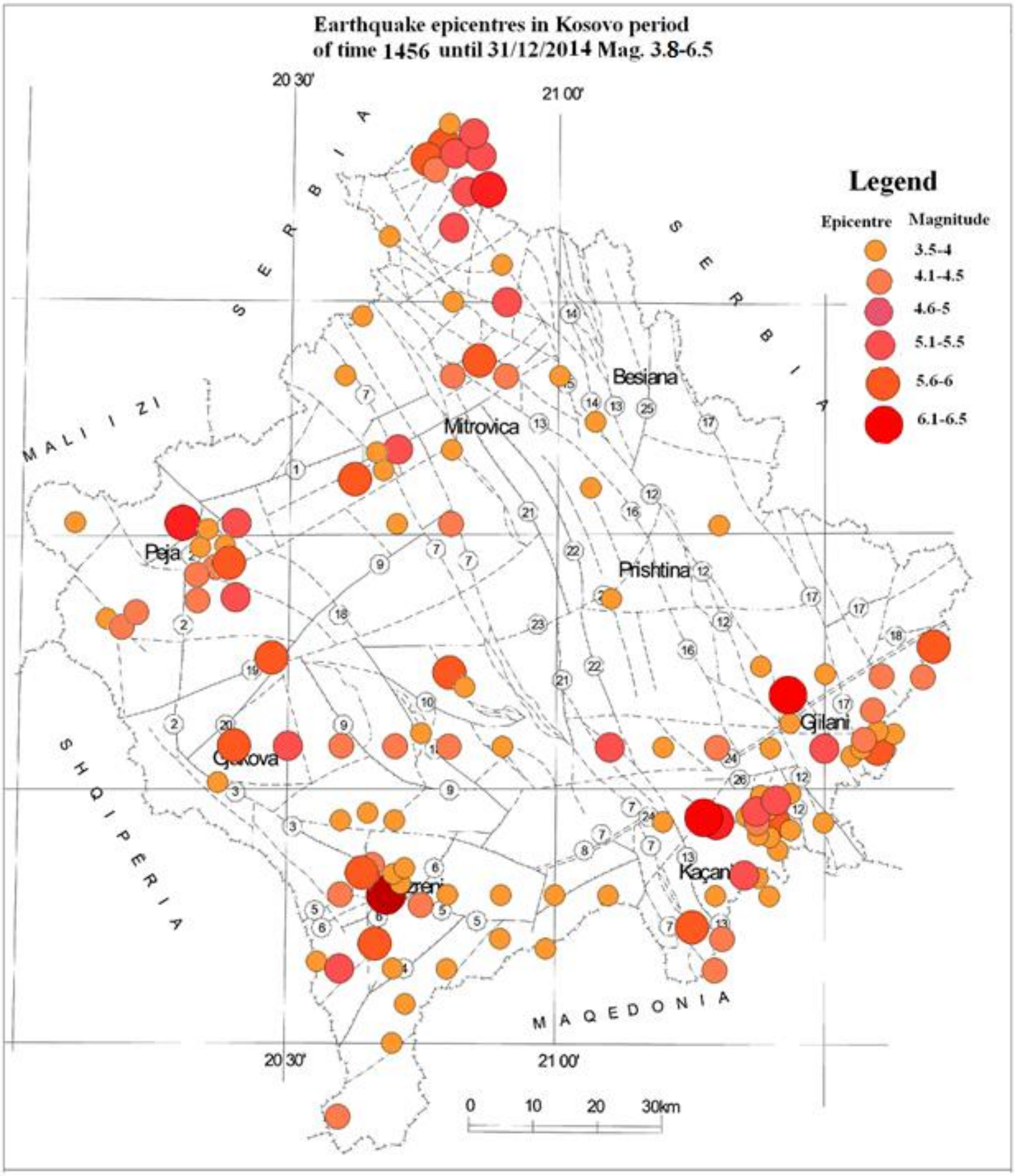



**Figure 1.** Active faults and earthquake epicentres in Kosovo with magnitude M≥3.5 for the period of time 1456 until 31/12/2014

In order to generate simulated time histories some parameters should be predefined (Table 2) based on the knowledge of the characteristics of the earth's crust beneath the territory of Kosova, type and orientation of the faults and other seismologic and geophysics data.

**Table 2.** Some seismological parameters

| **Fault ID number** | **1** | **2** | **3** | **6** | **7** | **12** | **15** |
|---|---|---|---|---|---|---|---|
| **Fault strike and dip (deg)** | 90 | 90 | 90 | 90 | 90 | 90 | 90 |
| **Fault size (km)** | 35 | 50 | 45 | 50 | 30 | 55 | 45 |
| **Depth of upper edge (km)** | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| **Subfault size (km)** | | | | 1*1 | | | |
| **Crustel shear –wave velocity (km/s)** | | | | 3.7 | | | |
| **Crustel density (g/cm3)** | | | | 2.8 | | | |
| **Rupture velocity** | | | | 0.8 * Beta | | | |
| $\mathbf{M_{observed}}$ | 6.0 | 6.0 | 5.3 | 6.0 | 6.1 | 6.1 | 5.1 |
| $\mathbf{M_{max}}$ | 6.1 | 6.1 | 6.1 | 6.1 | 6.5 | 6.5 | 5.5 |

**Beta refers to crustal shear velocity*

## Results of Analysis

The main objective is to simulate the near-fault strong motion records. Simulation of ground motions is carried out using stochastic model of Boore (2003). Due to unavailability of strong recorded ground motion, the stochastic method proposed by Boore (2003) is applied to simulate the acceleration time histories. Synthetic displacement time histories should be compatible with the tectonic environment and earthquake magnitude of the simulated event. The proposed methodology has the following steps:

1. Select the moment magnitude, MW, of the potential earthquake and calculate the prevailing frequency, fP, by fP=1/TP. For selected values of the parameters A, γ and ν (or for a suite of values of these three parameters), generate the coherent component of acceleration time istory (or a suite of time histories) using equation.
2. For the selected fault–station geometry, generate the synthetic acceleration time histories for the moment magnitude, MW, specified previously, using the specific barrier model.
3. Calculate the Fourier transform of the synthetic acceleration time histories generated in steps 1 and 2.
4. Subtract the Fourier amplitude spectrum of the synthetic time history generated in step 1 from the Fourier amplitude spectrum of the synthetic time history produced in step 2.
5. Construct a synthetic acceleration time history so that (a) its Fourier amplitude spectrum is the difference of the Fourier amplitude spectra calculated in step 4; and (b) its phase coincides with the phase of the Fourier transform of the synthetic time history generated in step 2.
6. Superimpose the time histories generated in steps 1 and 5. The near-source pulse is shifted in time so that the peak of its envelope coincides with the time that the rupture front passes in front of the station.

For fixed magnitude and distance, specific source, path, and site parameters are stress drop, crustal damping, and crustal shear-wave velocity profile. These represent the point-source ground-motion parameters for a rock site.

For strong ground motions, most of the elastic energy arrives coherently in a single, intense, relatively long period pulse at the beginning of record, representing the cumulative effect of almost all the seismic radiation from the fault. The phenomenon is even more pronounced when the direction of slip on the fault plane points toward the site as well. The input parameters of the model have an unambiguous physical meaning. It successfully simulates the entire set of available displacement, velocity, and (in many cases) acceleration time histories, as well as the corresponding deformation, velocity, and acceleration response spectra.

In order to identify the influence of different parameters on the results of the simulation, a set of three simulations were performed, i.e. for the faults of interest and the corresponding maximum expected magnitude the simulation of ground motion time history is obtained for each location.

The obtained simulated time histories depend on distance, which is expected, but also depend strongly on the orientation of the active fault, i.e. the energy radiation pattern. Modeling of the strong ground motion is complicated problem since one does not know the source and structural models in such a detail to be able to compute deterministically the seismograms up to relatively high frequencies. Due to complexities of the real path effect, the simulations can be subjected to comparison just with dominant part of the observed record, usually main pulses composed of strongest phases. The real and synthetic seismograms cannot be compared” point by point” because of the stochastic character of the waveforms. They can be compared in terms of peak value, duration, the envelope, etc., or just ”by eye”.

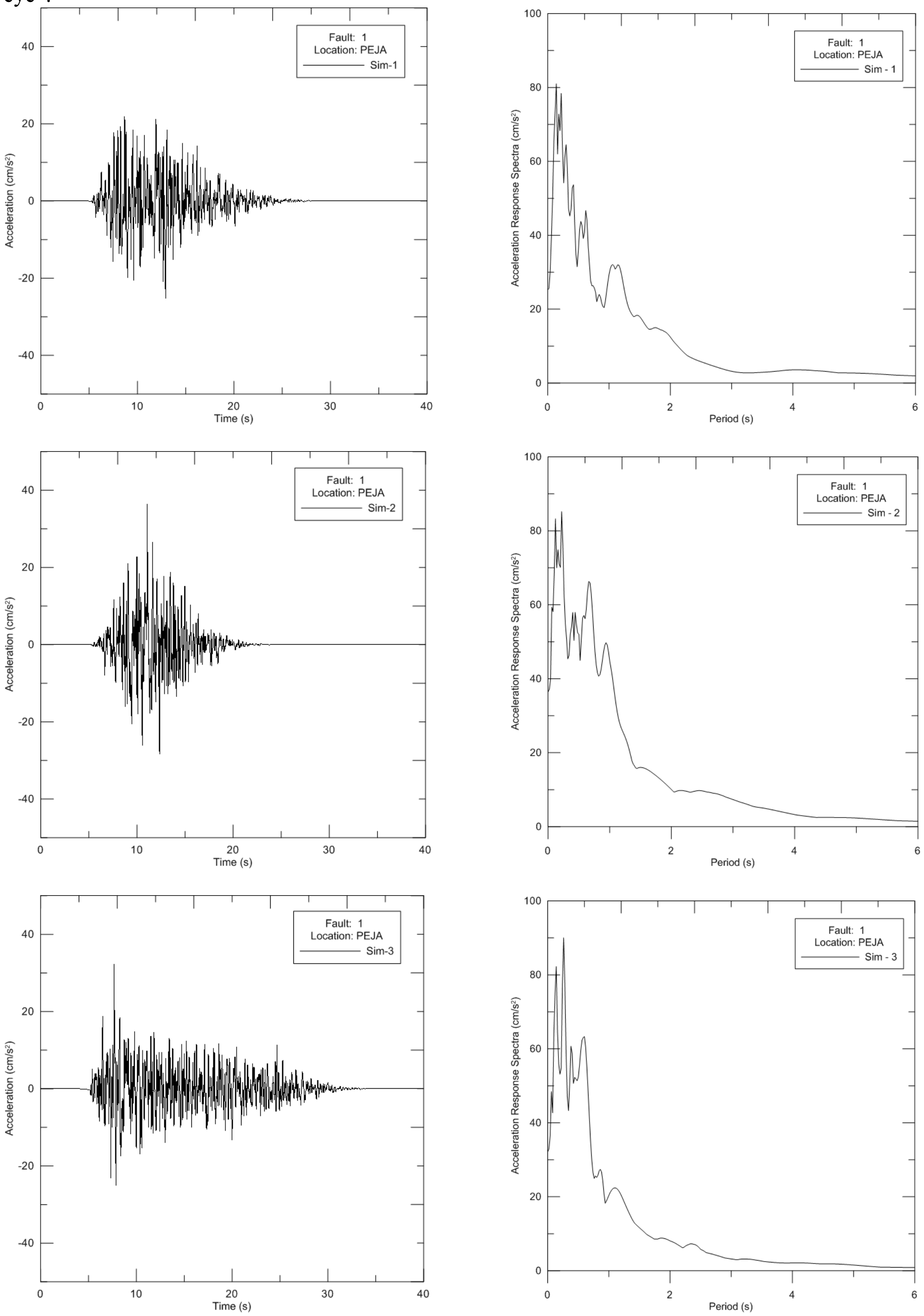


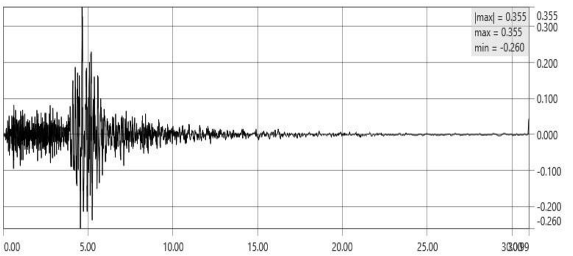

**Figure 2.** Simulated accelerations from Fault -1 to location PEJA, distance 30 km Max Magnitude 6.1

Comparisons of stochastic-method predictions with empirically-determined ground motions indicates that the stochastic method is useful for simulating mean ground motions having a specified magnitude and fault–station distance. The Istog earthquake of March 10, 2010, Ml = 5.1 is one of the strongest earthquakes recorded in Kosovo in the last 10 years that was felt on the whole territory of the state as well as in the neighbouring countries. It was generated by the Istoq seismic source characterized with a 30km long fault structure with nearly east-west direction. This earthquake was chosen for 'testing' of the method in order to see if it can be used to generate "usable" synthetic time histories. Recordings of the earthquake were obtained on six seismological stations of the Kosovo Seismologic Station Network (Table 3).

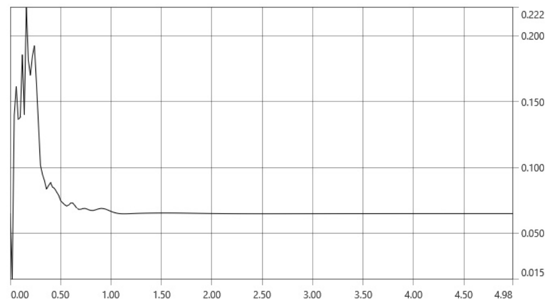
**Table 3.** Data on maximum acceleration recorded from Istog Earthquake and obtained from generated synthetic strong motion time histories

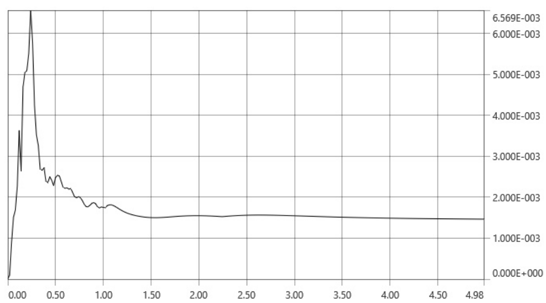
| Station | Chanel | Max. acceleration ($m/s^2$) | Distance from epicentre (km) | Acc $m/s^2$ NEW | Sint Acc $m/s^2$ New |
|---|---|---|---|---|---|
| | HNZ | 0.0853 | | 0.0649 | 0.2300 |
| **PEJK** | HNN | 0.3552 | 30 | 0.3450 | 0.3640 |
| | HNE | 0.1862 | | 0.1780 | 0.2620 |
| | HNZ | 0.0378 | | | |
| **ZATK** | HNN | 0.1167 | 33 | | |
| | HNE | 0.1315 | | | |
| | HNZ | 0.0126 | | | |
| **PRZK** | HNN | 0.0143 | 60 | | |
| | HNE | 0.0256 | | | |
| | HNZ | 0.0172 | | 0.0167 | 0.0373 |
| **GJIK** | HNN | 0.0242 | 75 | 0.0234 | 0.0408 |
| | HNE | 0.0186 | | 0.0185 | 0.0350 |

Real time history recorded at PEJA location, Istog earthquake of March 10, 2010, Ml=5.1.




Acceleration [sec]-[m/sec$^2$]





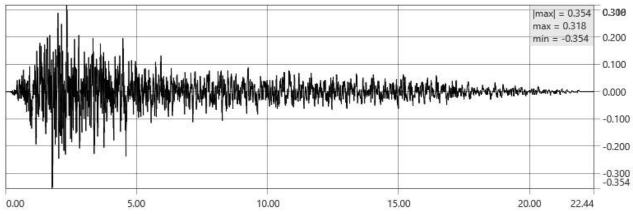
Acceleration Spectar [sec]-[m/sec$^2$] Velocity Spectar [sec]-[m/sec]

**Figure 3.** Time history obtained from Istog Earthquake recorded at location station **PEJA**, component N

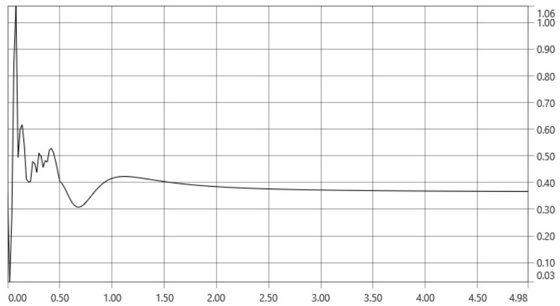
Synthetic time history generated at PEJA location with magnitude and epicentral distance same as Istog earthquake of March 10, 2010, Ml = 5.1. The characteristic of the fault that generated the Istog earthquake are known, as well as the fault plane solution and other data necessary for obtaining synthetic acceleration time histories for event with this magnitude. The simulation was performed on location of two stations.

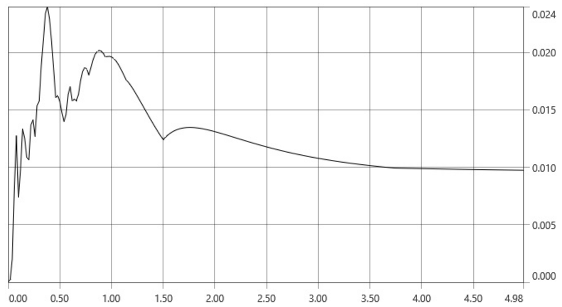
The spectral analysis of the obtained synthetic time histories was performed with 5% damping. Presented are real time history of Istog earthquake recorded at PEJA station and corresponding acceleration and velocity spectra (Figure 3) and synthetic time history generated on the same location

(Figure 4). Generally, the maximum acceleration values of the synthetic time histories are comparable to those of the real time histories (Table 3). Also the power spectra from the real and synthetic time histories show similar frequency content.




Acceleration [sec]-[m/sec$^2$]





Acceleration Spectar [sec]-[m/sec$^2$]  Velocity Spectra [sec]-[m/sec]

**Figure 4.** Synthetic Time History, acceleration and velocity spectra for location Peja, componente N

**Conclusions**

From the inspection of the corresponding figures and their comparison it can be concluded that:

1. Duration of the strong movement for both real and synthetic time histories that were analysed is comparable.
2. The real and synthetic time histories have similar power spectra, with different distribution of maximum amplitudes over the frequency range.
3. The acceleration spectra have similar pattern of maximum amplitudes distribution, up to period of 0.5s -1.5s for real and synthetic time histories.
4. Velocity spectra are also similar for both cases.
5. The acceleration and velocity spectra show quite limited frequency content.

Overall conclusion is that although the simulation method is far from being perfect, it can be used for generating synthetic time histories that will reflect the regional tectonic, seismic and geologic conditions.

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