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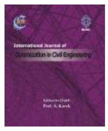

GENERATION OF MULTIPLE SPECTRUM-COMPATIBLE ARTIFICIAL EARTHQUAKE ACCELEGRAMS WITH HARTLEY TRANSFORM AND RBF NEURAL NETWORK

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ABSTRACT

The Hartley transform, a real-valued alternative to the complex Fourier transform, is presented as an efficient tool for the analysis and simulation of earthquake accelerograms. This paper is introduced a novel method based on discrete Hartley transform (DHT) and radial basis function (RBF) neural network for generation of artificial earthquake accelerograms from specific target spectrums. Acceleration time histories of horizontal earthquake ground motion are obtained by the capability of learning of RBF neural network to expand the knowledge of the inverse mapping from the response spectrum to earthquake accelerogram. In the first step, Hartley transform is used to decompose earthquake accelerograms, then a RBF neural network is trained to learn to relate the response spectrum to Hartley spectrum. Finally, the generated accelerogram using inverse discrete Hartley transform is obtained from target spectrum. Approximately 200 uniformly scaled horizontal ground motion records from recent Iran's earthquakes are used to decompose with real Hartley transform and train networks.

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1. INTRODUCTION

In recent years, dynamic analysis of structures, either time-history of earthquake ground motion or response spectrum has grown considerably. Time histories also are used to

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correlate ground motion characteristics to structural and non-structural damage. In addition, for designing critical or major structures such as power plants, dams, and high-rise buildings, usually the final design is based on the complete time-history analysis.

In most cases, it is very unlikely that recorded ground motions will be available for all sites and conditions of interest. Hence, accurate methods for the simulation of earthquake ground motion throughout a region that utilize ground motions from previous earthquakes and recorded motions from the earthquake that has just occurred and according to a design spectrum is needed. Simulated accelerograms should have two important characterizes: first, be according to a specific design spectrum and second, have compatible geotechnical characteristics with desired area. There are so many methods for generating spectrum-compatible artificial earthquake accelerograms. Many researchers generate artificial accelerograms by modifying available accelerograms. These methods include applying a constant scalar to well-populated data banks [1, 2] or modifying them in time or frequency-domain. In the time-domain approaches usually recorded time histories passed through filters (e.g. Kanai-Tajimi filter) to alter the amplitude or frequency content over time. By using simple Fourier analysis and calculating the Fourier amplitude and phase angle spectra of historical accelerograms and then modifying the phase angle spectra, spectrum-compatible accelerograms with similar frequency content but different temporal characteristics can be obtained [3].

These methods applied to the analysis and simulation of earthquake records are based on the use of the discrete Fourier transform, whose success is largely due to the existence of efficient algorithms that known as fast Fourier transform (FFT) algorithms, for their computation. Nevertheless, the practical use of Fourier methods shows some drawbacks in the analysis of time series that observed in nature. Especially, while signals observed in most real-word applications are real-valued the Fourier transform, transforms a sequence of real data from the time-domain into a sequence of complex numbers in the frequency-domain. So, half of the numbers in the frequency-domain correspond with the information in the negative frequencies and are the same as the information contained in the positive frequencies. Additionally, this means that FFT algorithm required twice memory space of a real array. Furthermore, the multiplication of two complex numbers requires four real multiplications and two real additions. Consequently, due to the extra information, the amount of memory required and the number of computations needed, it seems obvious that the complex Fourier transform is not the most efficient method to transform real time series into the frequency domain.

Hartley proposed a real transform to avoid the time and memory computation shortcomings related to the complex Fourier transform of real data. This transform was expressed in a more symmetrical form between the function of the real variable and its transform. Nevertheless, because of introduction of discrete Cosine transform a little after Hartley transform and the similarity of them, Hartley transform remain unknown between researchers [4,7].

The main purpose of the present paper is to introduce the Hartley transform as an efficient tool and convenient alternative to the traditional complex Fourier transform for analysis and simulation of earthquake records and comparing the results with wavelet transform.

2. THE HARTLEY TRANSFORM

The integral Fourier transform of a continuous function of time $x(t)$ is given by [5]:

$$F_x(f) = \int_{-\infty}^{\infty} x(t) e^{-i2\pi ft} dt \tag{1}$$

The inverse transform define as:

$$x(t) = \int_{-\infty}^{\infty} F_x(f) e^{i2\pi ft} df \tag{2}$$

and the kernel transform function is:

$$e^{\pm i2\pi ft} = \cos(2\pi ft) \pm i \sin(2\pi ft) \tag{3}$$

In engineering problems, for using Eqs. (1) and (2) we should discrete data over a finite range. Therefore, a discrete approximation of above equation is needed. The discrete Fourier transform (DFT) define as [6]:

$$F_x(k) = F(k\Delta f) = \sum_{n=0}^{N-1} x(n) e^{-i2\pi k\Delta f n\Delta t} \qquad k = 0,1,...,N-1 \tag{4}$$

Where N is the number of samples, Δt, the constant sampling period, and $T = N\Delta t$, the total duration of the digitized time series, and also for a fixed N, the time and frequency increments are constrained by $\Delta f \Delta t = 1/N$. The original time series can be calculated by IDFT that written as:

$$x(n) = \frac{1}{N} \sum_{k=0}^{N-1} F_x(k) e^{i2\pi kn/N} \qquad n = 0,1,...,N-1 \tag{5}$$

In the engineering applications, there are signals that are limited, but have unlimited energy, for example periodic functions. So, we cannot use Eq. (1) for their Fourier transform. For this functions, we can either assume a period of signal and solve the problem or use the Stieltjes integration instead of Lebesque integration. We assume here that $x(t)$ has limited energy.

The Hartley transform of a real-valued function $x(t)$ defined as [6]:

$$H(f) = \int_{-\infty}^{+\infty} x(t) cas(2\pi ft)\, dt \tag{6}$$

and the inverse Hartley transform given by:

$$x(t) = \int_{-\infty}^{+\infty} H(f)cas(2\pi ft)df \tag{7}$$

where the kernel function of Hartley transform is defined as:

$$cas(x) = \cos(x) + \sin(x) \tag{8}$$

It is interesting to note that the Hartley transform has a self-inverse property that means the direct and inverse of transformations use the same integral operation [7].

Just like the Fourier transform, the practical use of the Hartley transform equations (Eqs. (6) and (7)) of the sampled real-valued finite time series x(n) requires the use of discrete approximations. The discrete Hartley transform (DHT) is given by [6]:

$$H(k) = H(k\Delta f) = \sum_{n=0}^{N-1} x(n)cas(2\pi k\Delta fn\Delta t) \qquad k = 0,1,...,N-1 \tag{9}$$

The inverse discrete Hartley transform (IDHT) can be written as:

$$x(n) = \frac{1}{N}\sum_{n=0}^{N-1} H(k)cas(2\pi kn/N) \qquad n = 0,1,...,N-1 \tag{10}$$

Note that Eqs. (9) and (10) have exactly the same form, except for a scaling factor of $1/N$. This implies that the forward and inverse transforms satisfy the self-inverse property. As a consequence, both the DHT and the IDHT can be computed by using the same algorithm. Furthermore, while the Fourier transform of a real signal is a complex function, the Hartley transform of a real function is also real because of the real nature of the cas function [7].

3. THE RBF NEURAL NETWORK

A radial basis function (RBF) network is an artificial neural network that uses radial basis functions as activation functions. It is a linear combination of radial basis functions. RBF networks typically have three layers: an input layer, a hidden layer with a non-linear RBF activation function and a linear output layer. The architecture of a radial basis function network can be shown as Fig.1. In comparison with back propagation networks, RBFs have several advantages. They usually train much faster than back propagation networks. Also, they are less susceptible to problems with non-stationary inputs because of the behavior of the radial basis function hidden units.

In a RBF network, there are three types of parameters that need to be chosen to adapt the network for a particular task: the center vectors, the output weights, and the RBF width parameters. In the sequential training of the weights are updated at each time step as data streams in. For some tasks, it makes sense to define an objective function and select the parameter values that minimize its value.

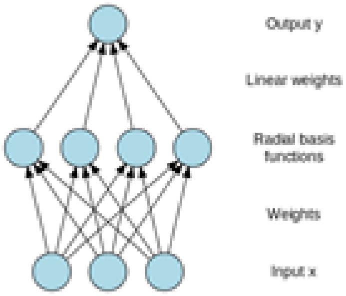

Figure 1. Architecture of a radial basis function network.

4. PROPOSED METHOD

The studies of Fourier, energy, power, and response spectra show that though the patterns of different earthquake records are not similar even in a specified area, but a certain pattern of response spectra could often be attained for the specified area because of their similarities [8].

The main objective of this paper is to analysis earthquake records with Hartley transform and training neural networks that are capable of generating multiple accelerograms for specified input response spectrum that includes the site geology specifications of a specified site. The generated accelerograms should have response spectrums closely approximate to the input response spectrum. In addition, the other characteristics of the generated accelerograms, such as their duration, should be similar to those of the recorded accelerograms used to train the neural networks.

4.1 Input earthquake accelerograms

One of the most important factors that influenced earthquake ground motions is local soil conditions. Recent studies of the influence of site geology on ground motion use the average shear wave velocity to identify the soil category. Also, there is a general agreement among various investigators whom the soil condition has a pronounced influence on velocities and displacements, thus larger peak horizontal velocities are to be expected for soil than rock [9,10]. This important factor is not taken in the models of previous related works. So, we categorizing earthquake records into two groups named Soil and Rock according to Iranian seismic design code [11]. According to this category soil with $375 \le V_S$, named Rock and others with $375 > V_S$, are Soil.

Then, we categorize all record into four duration groups of 10, 20, 30 and 40 seconds. For better result and faster training of NN, peak ground acceleration (PGA) of all accelerograms in each group shifted to make the PGA of each accelerogram aligned at the same time. This operation is performing by adding or deleting zeros from the start or end of accelerograms in specified manner so navigates of them not changed. Next, PGA of all the accelerograms were scaled to 1g so we could compare their response spectrum. In Tables 2 to 8 all records and categorizes that used for training RBF networks are shown. Note that researchers for Soil group with 10 seconds duration could not find any suitable records.

Table 1: Site Geology according to Iranian seismic design code [11].

Ground type	Explanation of materials	Shear wave velocity (m/s)
I	Un-weathered igneous rocks, hard sedimentary rocks and metamorphic rocks (as gneisses and crystalline silicate rocks)	$V_S>750$
	Very hard conglomerates very compact and very hard sediment	$375<V_S<750$
II	Soft igneous rocks e.g. tuffs, clay stones, shale and semi-weathered or altered rocks Crushed (but not hardly) hard rocks , foliated metamorphic rocks, conglomerate and compact sand and gravel	$375<V_S<750$
III	Weathered rocks, semi-compact sands and gravels, other compact sediments Compact sandy clay soils, with low ground water level	$175<V_S<375$
IV	Soft sediments, clay soils, weak cemented and un-cemented sands, incompact soils with high ground water level Any kind of soft soils	$V_S<175$

Table 2. List of earthquake records used as training set of ANN, group of 10 sec duration, Site geology: Rock [12].

Earthquake	Station	Date	Magnitude M_S	Modified PGA (cm/sec^2)	Duration (sec)
NAGHAN	NAGHAN	1977.04.06	6.2	761	9
	TABAS	1978.09.17	4.8	93.5	8.34
	SHALAMZAR	1984.06.01	5	337.2	8.4
	SARI	1990.01.20	5.8	143.1	9.2
	HOSSEINEH OLYA	1994.07.31	5	180.5	7.6
	SADABAD	1996.01.24	4.6	32.8	8.4
	KARIQ	1997.03.02	5	264.3	7.6
	HAMEDAN	1998.08.24	4.5	27.6	8.3
	NAHAVAND	1998.08.25	4.5	84	7.9
	DAM(HINY MINY)	1998.10.04	4.8	359	6
	CHENAR	1998.10.04	4.8	20.1	9.6
	KHONJ	1998.11.13	5.1	397.3	9.6
	AHRAM	1999.09.24	4.7	143.2	9
	AHRAM	1999.09.25	4.6	38.4	9.74
	AHRAM	1999.09.25	4.6	15.5	9.84
	Faryab	2000.03.11	4.3	23.9	9
	Tange Eram	2001.05.06	4.2	38.2	9
	Borazjan	2001.05.07	4.2	27.6	8.1
	Roodbar	2001.08.20	4.1	27.9	6.4
	Bandar-e-Asaluyeh	2002.02.27	4.2	48.6	6.9
	Tange Eram	2002.06.23	4	65.9	7.4
	Sirch	2003.04.16	4.2	75.2	8

Table 3. List of earthquake records used as training set of ANN, group of 20 sec duration, Site geology: Rock [12].

Earthquake	Station	Date	Magnitude M_S	Modified PGA (cm/sec^2)	Duration† (sec)
	SIRCH	1989.11.20	5.7	65	18.3
	ZARRAT	1994.06.18	5	111.5	18
	ZANJIRAN	1994.06.18	5	87.8	18
ZANJIRAN	ZARRAT	1994.06.20	5.9	310.5	20
ZANJIRAN	ZANJIRAN	1994.06.20	5.9	886.8	14.4
ZANJIRAN	SERVESTAN	1994.06.20	5.9	12.6	20
	HOSSEINEH OLYA	1994.07.31	5.3	163.8	17.8
SAREIN	NIR (KARSHENASI)	1997.02.28	6.1	38.7	15.6
SAREIN	KARIQ	1997.02.28	6.1	494.3	15.4
	NAMIN	1997.03.02	5	24.1	19.8
	HASHTPAR	1998.07.09	5.5	14	17.9
	DAM (SATARKHAN)	1998.07.11	5.5	15.1	17.3
	MALAKSHAHI	1998.08.05	4.9	12.1	19
	KOHNUSH	1998.08.28	4.5	18	19.4
	MARUN DAM	1999.01.29	4.5	24.3	19.4
	BABAKALAN	1999.01.29	4.5	14.1	18.8
	BEHBAHAN	1999.01.29	4.5	12.1	18.1
	ABAD	1999.09.25	4.6	19.6	18.9
	DELVAR	1999.09.25	4.6	9.7	18.4
POL-E-ABGINEH	KAZEROON	1999.10.31	4.9	70.7	18.8
POL-E-ABGINEH	ROMGHAN	1999.10.31	4.9	13.8	18.1
POL-E-ABGINEH	BALADEH	1999.10.31	4.9	59.9	18.1
	GORGAN	1999.11.26	4.6	11	19.6
	BARDESKAN	2000.03.28	4.8	21.9	20
	SEPIDAN	2000.06.23	4.5	15.2	18.6

Table 4. List of earthquake records used as training set of ANN, group of 30 sec duration, Site geology: Rock [12].

Earthquake	Station	Date	Magnitude M_S	Modified PGA (cm/sec^2)	Duration† (sec)
	MAKU	1976.11.24	7.3	91.5	28
	SEDEH	1979.01.16	6.8	41.2	28
	TABAS	1980.01.12	5.8	160.8	28.6
	FIRUZABAD	1994.06.20	5.9	239	22
ZANJIRAN	MOHARLO	1994.06.20	5.9	22.3	25
SAREIN	NIARAQ	1997.02.28	6.1	23	25.4
SAREIN	NAMIN	1997.02.28	6.1	71.1	29.8
SAREIN	KHK (FARMD)	1997.02.28	6.1	18.9	21.8
SAREIN	KJH(BAHK.)	1997.02.28	6.1	8.3	23
	NIR	1998.07.09	5.5	18.6	23.2

	AHAR	1998.07.09	5.5	19.1	25.6
	NIARAGH	1998.07.09	5.5	32.8	20.5
	DAMIRCH	1998.07.13	5.5	41	24
	BAHAR	1998.08.22	4.5	9.8	21.7
	BORUJARD	1998.08.23	4.5	13	22.2
	SFANDAN	1998.08.28	4.5	15.4	23
	SFANDAN	1998.08.29	4.5	15.4	22.6
	PATAVEH	1998.09.21	4.6	56.3	25.6
	FEDAGH	1998.11.13	5.1	18.7	24
KAREBAS	SHABANKAREH	1999.05.06	6.3	10.7	23
KAREBAS	ABAD	1999.05.06	6.3	8.1	26.9
KAREBAS	DELVAR	1999.05.06	6.3	10.2	23
KAREBAS	KAVAR	1999.05.06	6.3	10.8	24.3
KAREBAS	MAHARLO	1999.05.06	6.3	13.1	24.3
KAREBAS	ZARRAT	1999.05.06	6.3	10.6	26.9
	ABAD	1999.09.24	4.7	47.9	26.2
	DELVAR	1999.09.24	4.7	100.3	24.3
POL-E-ABGINEH	GHAEMIYEH	1999.10.31	4.9	50.9	23.1
	MARAVEHTAPEH	1999.11.26	4.6	9.9	23
	RAZ	2000.08.22	5.8	62.5	24.8

Table 5. List of earthquake records used as training set of ANN, group of 40 sec duration, Site geology: Rock [12].

Earthquake	Station	Date	Magnitude M_S	Modified PGA (cm/sec^2)	Duration† (sec)
TABAS	DEYHUK	1978.09.16	7.3	296.8	40
TABAS	TABAS	1978.09.16	7.3	817.8	38
	TORBATHYDARIYEH	1979.11.27	7.3	45.7	39.8
	BAJESTAN	1979.11.27	7.3	110.9	32.6
	SEDEH	1979.11.27	7.3	82.2	38
	KHAF	1979.11.27	7.3	129.2	40
Manjil-Rudbar	AB-BAR	1990.06.20	7.4	557.7	35
	Shabankareh	1996.01.24	4.5	53.4	32.3
SAREIN	RAZI	1997.02.28	6.1	34.4	32.8
SAREIN	HUR(BAKH.)	1997.02.28	6.1	58.7	37.4
	PSA	1998.07.09	5.5	41.2	36.7
KAREBAS	KAZEROON	1999.05.06	6.3	28.2	36.8
KAREBAS	CHENARSHAHIJAN	1999.05.06	6.3	36.1	40
Changureh-Avaj	BAHAR	2002.06.22	6.4	32.8	34.5
Changureh-Avaj	NAHAVAND	2002.06.22	6.4	25.8	36.4
BAM	Sirch	2003.12.26	6.7	30	40
BAM	Andoohjerd	2003.12.26	6.7	30.7	32
	AB-BAR	2004.05.28	6.3	34.8	40
SILAKHOR	Nahavand	2006.03.31	6.4	18	32.8
SILAKHOR	Hamedan5	2006.03.31	6.4	23.8	37.8

Table 6. List of earthquake records used as training set of ANN, group of 20 sec duration, Site geology: Soil [12].

Earthquake	Station	Date	Magnitude M_S	Modified PGA (cm/sec^2)	Duration (sec)
	RUDSAR	1980.12.03	4.7	105.4	18.3
	RAVAR	1981.07.28	7	65.7	14.4
	GOLBAF	1989.11.20	5.7	293.73	12.1
Manjil-Rudbar	ROUDSHOR	1990.06.20	7.7	41.2	18
	MEIMAND	1994.06.18	5.7	401.7	16.6
SAREIN	MIYANEH	1997.02.28	6.1	12	20
	KHOMARLU	1998.07.09	5.5	16.2	19.42
	KALEYBAR	1998.07.09	5.5	12	20
	ASL	1998.07.09	5.5	12.5	17.9
	EKBATAN DAM	1998.08.21	4.5	10.1	16.66
	GIUAN	1998.08.21	4.5	24.6	19.34
SALEHABAD	GONBADLI	1998.11.08	5.2	17.2	18.94
	JOSHAN	1998.11.18	4.9	20	19.72
	KERMAN	1998.11.18	4.9	24.8	19.42
	GUYOM	1999.05.06	5.7	11.3	18.86
	BABAMONIR	1999.05.06	6.3	38.6	20
POL-E-ABGINEH	NURABADMAMASANI	1999.10.31	4.9	14.9	19.86
	KALALEH	1999.11.19	5.1	11.2	20
	ALIABAD	1999.11.26	4.6	303.3	13.62
	KASHMAR	2000.02.02	5.3	17.5	20
	KASHMAR	2000.03.28	4.9	12.4	19.76
	BEHSHAHR	2000.08.16	4.5	8.7	20
	B-TORKAMAN	2000.08.16	4.5	23.03	18.98
	RAZ	2000.09.19	4.7	23	19.76
Changureh-Avaj	AVAJ	2002.06.22	6.4	495.9	13
KAHAK	Gazoran	2007.06.18	5.4	77.2	19.7
KAHAK	Hassan Abad	2007.06.18	5.4	38.6	19.94
KAHAK	Shahriyar	2007.06.18	5.4	9.8	19.86
KAHAK	TEHRAN 11	2007.06.18	5.4	11.5	19.72
KAHAK	Qani Abad	2007.06.18	5.4	14.7	18.2

Table 7. List of earthquake records used as training set of ANN, group of 30 sec duration, Site geology: Soil [12].

Earthquake	Station	Date	Magnitude M_S	Modified PGA (cm/sec^2)	Duration[†] (sec)
	GHAEN	1979.11.27	7.3	195.4	29.28
ZANJIRAN	BABANAR	1994.06.20	5.9	28.2	24.24
SAREIN	MESHKINSHAHR	1997.02.28	6.1	25.2	28.1
SAREIN	GERMY (KARSHENASI)	1997.02.28	6.1	43.5	25.7

	HERIS	1998.07.09	5.5	15.4	29.54
	BOJNORD	1998.08.04	5.1	29.3	24.26
	SALEHABAD	1998.08.05	4.9	27.9	22.96
	BEYRAM	1998.11.13	5.1	10.2	22.9
	EVAZ	1998.11.13	5.1	27.5	27.1
	KERMAN	1998.11.18	4.9	19.7	24.18
	DEHDASHAT	1999.01.29	4.5	45.7	29.32
	BANDARABAS	1999.03.04	6.4	15.3	26.8
KAREBAS	KAPHTARAK	1999.05.06	6.3	14.6	26.14
KAREBAS	ZARGHAN	1999.05.06	6.3	11.2	21.74
KAREBAS	SHIRAZ 3	1999.05.06	6.3	14.1	26.9
KAREBAS	SHIRAZ 2	1999.05.06	6.3	28.96	29.6
KAREBAS	SHIRAZ (GEO)	1999.05.06	6.3	14.1	27
SALEHABAD	NASRABAD	1999.11.08	5.2	15.7	26.86
	RAMIYAN	1999.11.19	5.1	24.4	30
	VOSHMGIR	1999.11.19	5.1	39.6	29.32
	MOHAMADABAD	1999.11.19	5.1	10.2	23.02
	AGHGHALA	1999.11.19	5.1	31.7	29.76
	AGHBAND	1999.11.19	5.1	13.5	27.88
	OROMIYEH	2000.06.26	5.2	16.9	21.54
Changureh-Avaj	GILVAN	2002.06.22	6.4	17.4	26.82
Changureh-Avaj	GHAHAVAND	2002.06.22	6.4	24.4	30
Bam	Shahdad	2003.12.26	6.7	19.9	30
Bam	Bam	2003.12.26	6.7	759.6	26.96
KAHAK	Panzdahe khordad	2007.06.18	5.4	41.6	28.38
KAHAK	Naragh	2007.06.18	5.4	20.6	29.9

Table 8. List of earthquake records used as training set of ANN, group of 40 sec duration, Site geology: Soil [12].

Earthquake	Station	Date	Magnitude M_S	Modified PGA (cm/sec^2)	Duration† (sec)
	KHAF	1979.11.14	6.7	80.95	38.9
	GONABAD	1979.11.27	7.3	73	39.94
	KHEZRI	1979.11.27	7.3	95.1	35.02
	KERMAN	1981.07.28	7	98.2	37.92
Manjil-Rudbar	ESHTEHARD	1990.06.20	7.4	76.5	40
GARMKHAN	BAREZO DAM	1997.02.04	6.8	41.6	35.76
SAREIN	ARDEBIL 1	1997.02.28	6.1	109.1	40
SAREIN	ASTARA	1997.02.28	6.1	42.8	40
SAREIN	ARDEBIL(MASKAN)	1997.02.28	6.1	160.2	39.3
GOLBAF	KERMAN 2	1998.03.14	6.9	40.1	39.5
GOLBAF	KERMAN 1	1998.03.14	6.9	35.5	37
	BIRJAND	1998.04.10	5.7	16.6	34.26
	MESHKINSHAHR	1998.07.09	5.5	22.7	31.98
	LALEHZAR	1999.03.04	6.4	15.3	33.26

KAREBAS	GUYOM	1999.05.06	6.3	37.2	36.52
KAREBAS	BABAMONIR	1999.05.06	6.3	13.4	39.66
Changureh-Avaj	BOOEIN ZAHRA	2002.06.22	6.4	18.7	40
Changureh-Avaj	ABHAR	2002.06.22	6.4	38.7	40
Changureh-Avaj	ESHTEHARD	2002.06.22	6.4	18.3	31.94
Bam	Joshan	2003.12.26	6.7	24.4	39.66
Bam	Kerman1	2003.12.26	6.7	18.3	38.86
Bam	Mohamad Abad	2003.12.26	6.7	117.9	38.44
Bam	Ravar	2003.12.26	6.7	12	38.38
Bam	Lale Zar	2003.12.26	6.7	12.8	35.36
Kojur Firoozabad	Tonekabon	2004.05.28	6.3	45.9	39.88
Silakhor	Khoram Abad	2006.03.31	6.4	35.3	39.89
Silakhor	Khondab	2006.03.31	6.4	50.9	36.48
KAHAK	Mamooniyeh	2007.06.18	5.4	34.6	40
KAHAK	Veshnaveh	2007.06.18	5.4	38.9	39.94
KAHAK	Raveh	2007.06.18	5.4	21.7	33.94

5. RESPONSE SPECTRUM

In the previous works, some researchers use pseudo-velocity response spectrum (PSV) as inputs [13] and others use pseudo-acceleration response acceleration (PSA) [14]. For present research, both PSV and PSA are used for training networks separately to compare the results and recognizing that which of them is more suitable for our purpose. The values of the response spectrums of accelerograms are calculated at 1001 discrete frequencies according to the following formula [15].

$$\ddot{x}(t) + 2\zeta\omega_l \dot{x}(t) + \omega_l^2 x(t) = -a_g(t), \tag{11}$$

$$PSV(\omega_l, \zeta) = \omega_l \max_t |x(t)|, l = 1, 2, 3, ..., 1000, \quad \zeta = 5\%, \tag{12}$$

$$PSA(\omega_l, \zeta) = \omega_l PSV(\omega_l, \zeta) = \omega_l^2 \max_t |x(t)|, l = 1, 2, 3, ..., 1000, \quad \zeta = 5\%, \tag{13}$$

where ω_l, ξ and $a_g(t)$ are the fundamental frequency and the damping coefficient of the single degree of freedom system and the earthquake ground acceleration, respectively.

6. TRAINING AND TESTING OF RBF NEURAL NETWORKS

As mentioned before the main subject of this paper is using ANNs to mapping a relation between response spectrum of training accelerograms and Hartley spectrum of them. Note that because of real nature of Hartley transform we do not have any imaginary numbers. So, ANNs easily trained.

For training, in each category we pick all records except two of them, randomly. Then, PSA and PSV and also Hartley spectrum of them will be calculated. Next, one time we train networks with PSV of records as input and Hartley spectrum of them as target. The other time we replace PSV with PSA and repeat the process.

After training we control the networks by testing them in two steps. First, calculate PSV and PSA of records that was in training groups. Then, we obtain Hartley spectrum of records from trained RBF neural network. After that, with taking inverse discrete Hartley transform (IDHT) of Hartley spectrum, simulated records are obtained. For this step original and simulated records and response spectra should be the same. Second, calculate PSV and PSA of two records that was not in training group. Finally, PSA and PSV of them are calculated so that we can control with PSA and PSV of original records.

7. INTERPRETIVE EXAMPLES

187 earthquake accelerograms recorded in Iran is used for training the ANNs, that all of these records were discretized at 0.005 seconds. Therefore, all accelerograms with durations of 10, 20, 30, and 40 sec. have 2001, 4001, 6001, and 8001 discrete points, respectively. PSA or PSV spectra of all accelerograms are calculated numerically, according to Equations 11 to 13 at 1001 equally spaced discrete period in the range of 0.01-10s, with 5% damping ratio (ζ=5%). Comparison between original and simulated records that were in trained groups are shown in Fig.2 and 3.

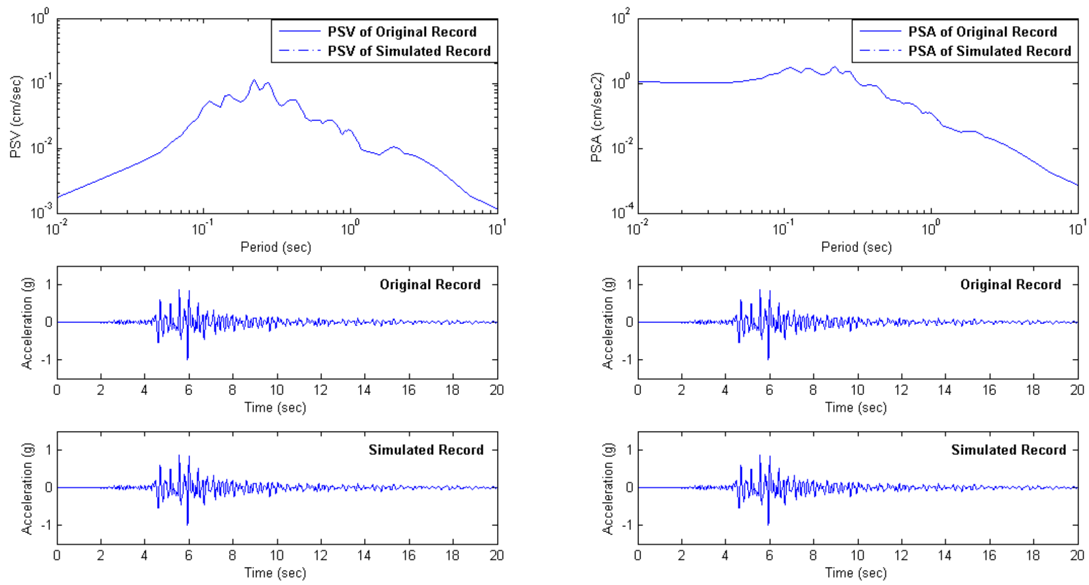

Figure 2. Controlling RBF network with train records, Zarat-1994, Rock, 20 sec.

As can be seen, the ANNs learn the relation between response and Hartley spectra very well and simulated and original records are exactly the same. In Fig.4 and 5 comparisons between records that were not in training group are shown.

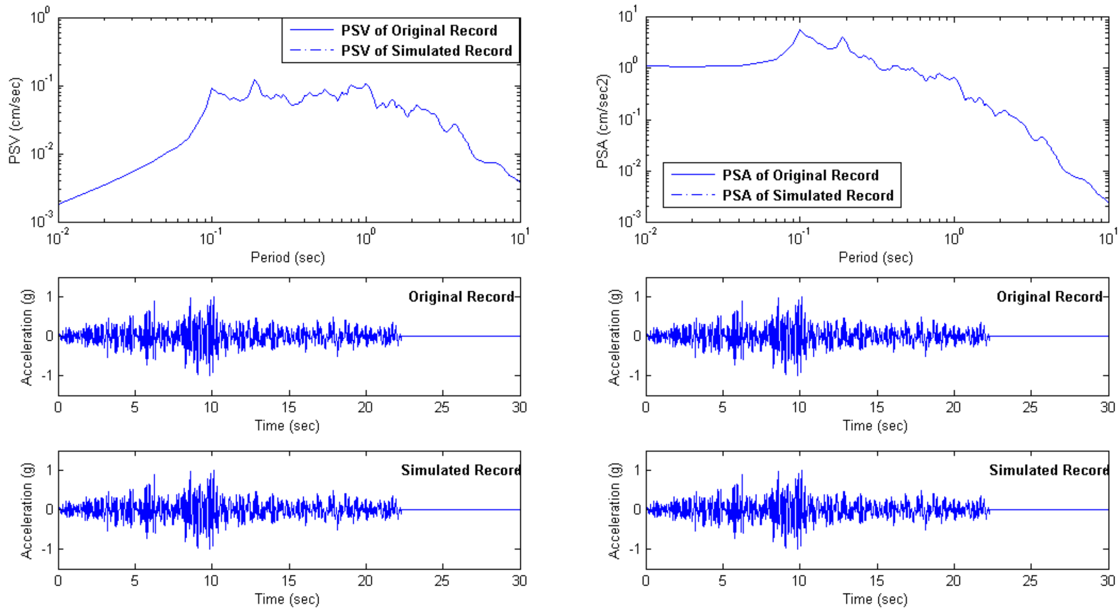

Figure 3. Controlling RBF network with train records, Nasrabad-1999, Soil, 30 sec.

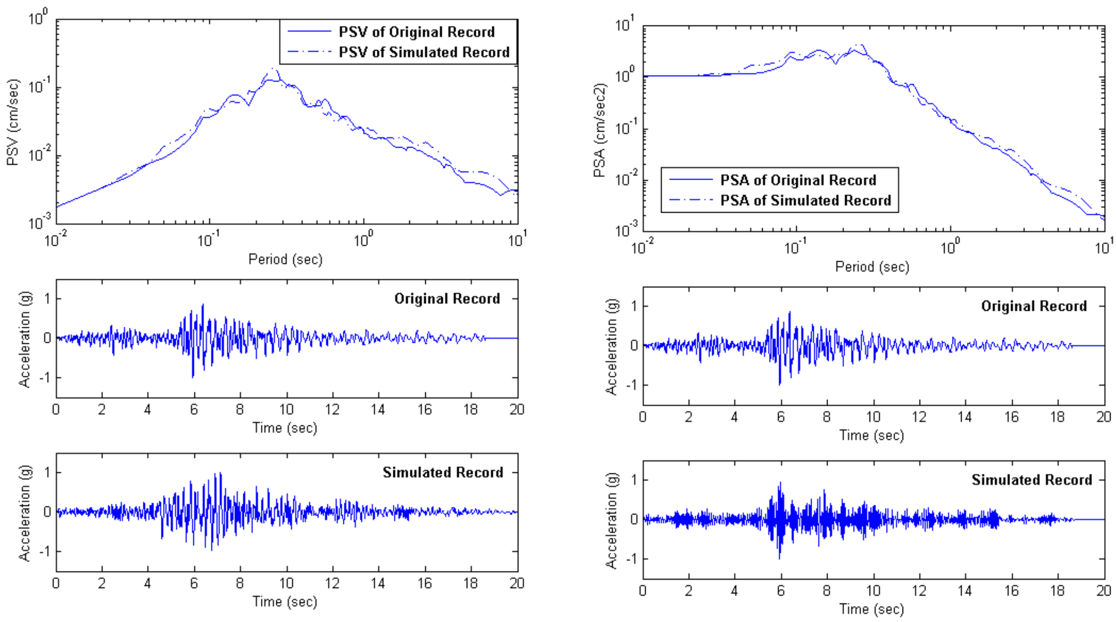

Figure 4. Controlling RBF network with train records, Sepidan-2000, Rock, 20 sec.

As can be seen, response spectra of simulated records for PSA and PSV are very similar to original records. So, it’s clear that RBF neural networks learns the relation between response and Hartley spectrum of records and can simulate them very well.

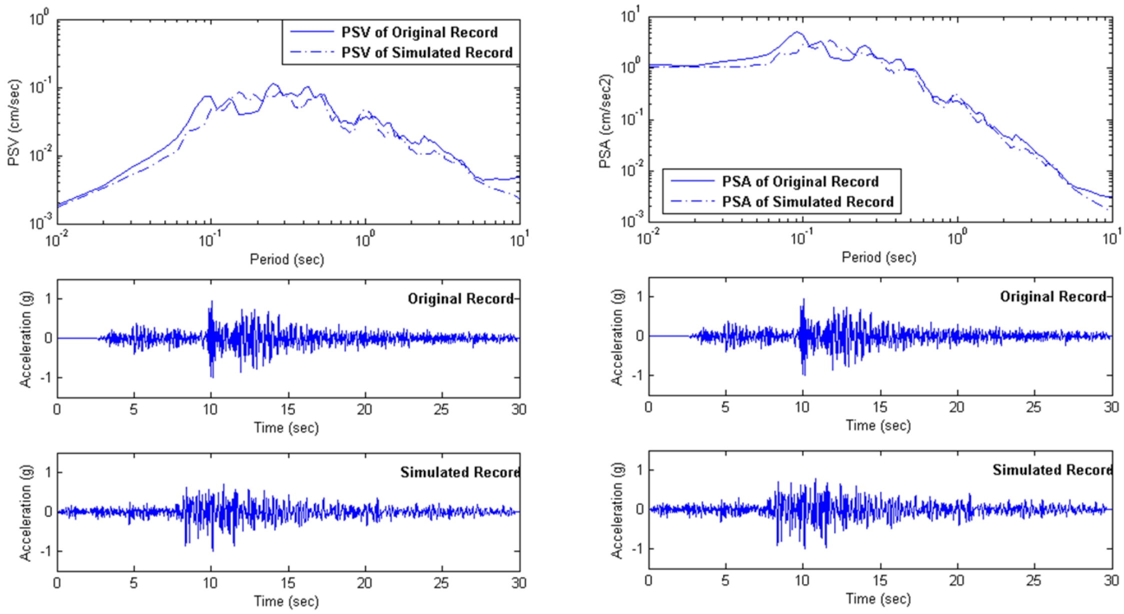

Figure 5. Controlling RBF network with train records, Naragh-2007, Soil, 30 sec.

Finally, figures 6 to 9 show the generated varied duration accelerograms from Newmark and Hall (Newmark & Hall, 1986) with PGA 1g and mean hazard level for Rock and Soil geology.

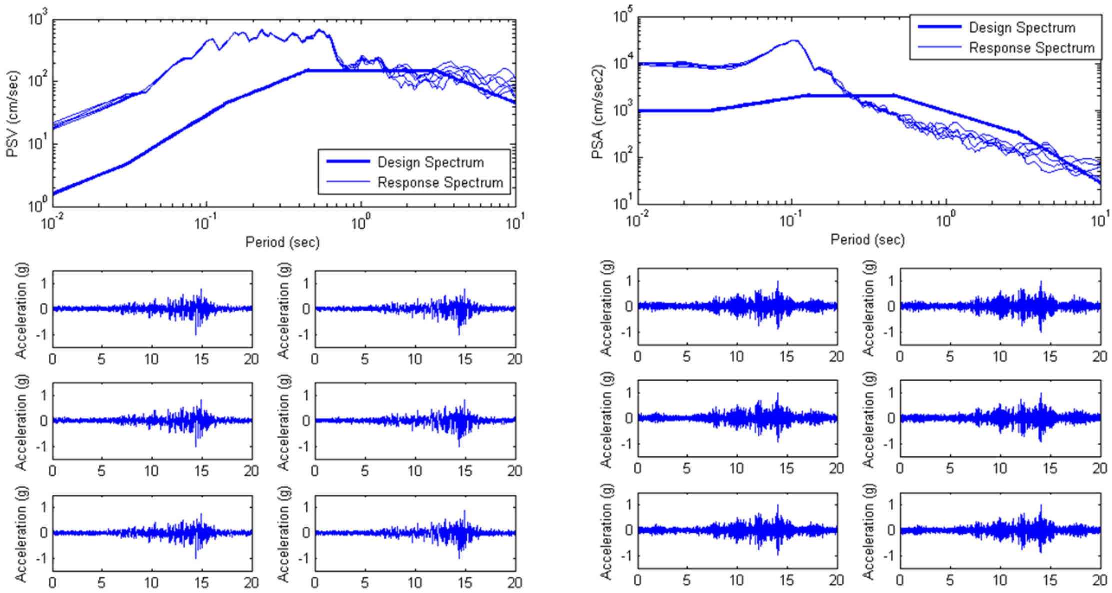

Figure 6. Generated 20 sec. accelerograms from Newmark and Hall design spectrum, Rock.

As shown in this figures, result from PSA and PSV are different. Also, artificial accelerograms from PSA are very noisy. Another matter is that the response spectrums of artificial accelerograms for period of 1 second and upper are similar to design spectrum approximately well.

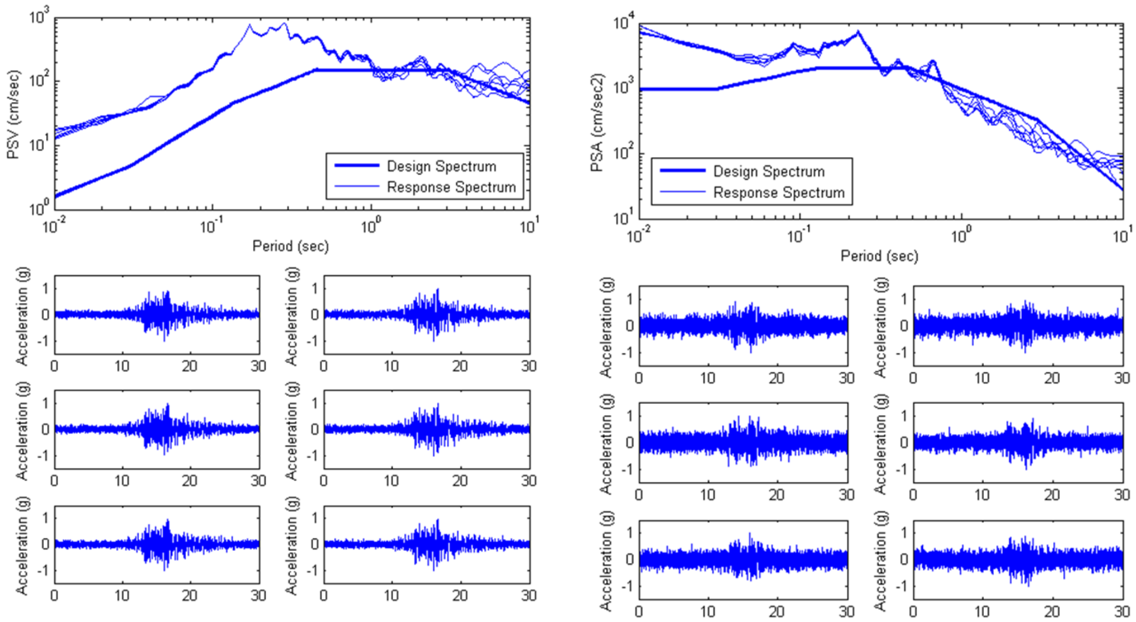

Figure 7. Generated 30 sec. accelerograms from Newmark and Hall design spectrum, Rock.

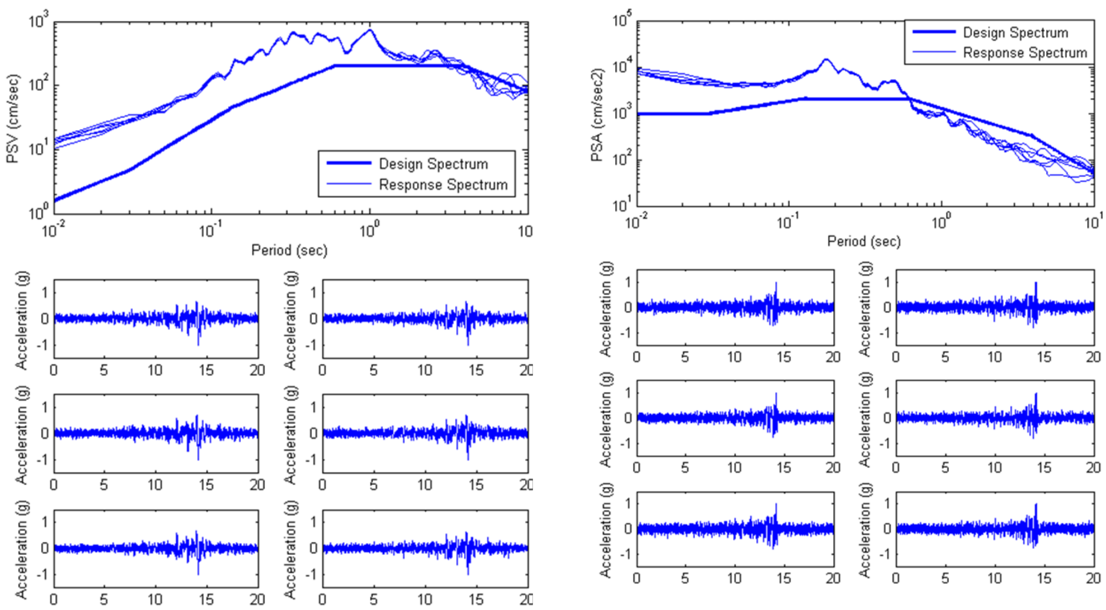

Figure 8. Generated 20 sec. accelerograms from Newmark and Hall design spectrum, Soil.

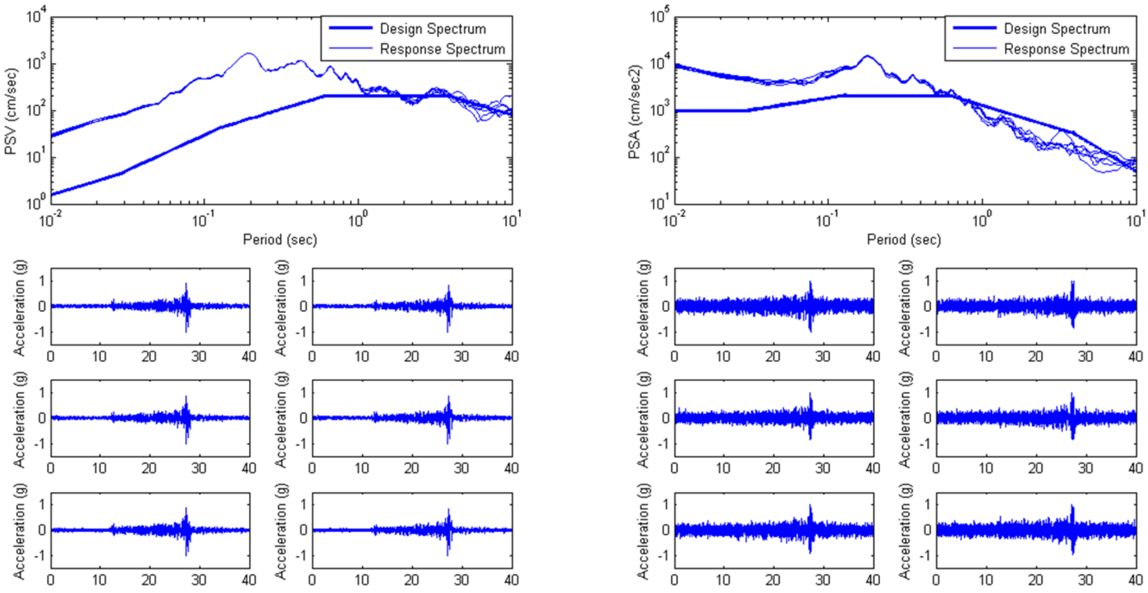

Figure 9. Generated 40 sec. accelerograms from Newmark and Hall design spectrum, Soil.

8. CONCLUSIONS

In this study, first a method of applying Hartley transform in analysing earthquake accelerograms introduced and then by using the capability of RBF neural networks in learning nonlinear problem, multiple spectrum-compatible artificial accelerograms for two site type of Rock and Soil are generated. 187 earthquake accelerograms recorded in Iran are used for training the ANNs, that all of these records were discretized at 0.005 sec. Then all these categorized according to their durations of 10, 20, 30 and 40 seconds. PSA or PSV spectra of all accelerograms are calculated numerically, according to Equations 11 to 13 at 1001 equally spaced discrete period in the range of 0.01-10s, with 5% damping ratio (ζ=5%).

The inputs of ANNs are PSA and PSV and targets of them are Hartley spectrum. After training and testing neural networks in each category (Figs 2 to 5), for given design spectra RBFs generate artificial acceleration with duration of their category (Figs 6 to 9).

The artificial accelerograms have accidental nature of real earthquake. But their response spectra match to the design spectra only for periods more than 1 sec. very well.

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