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CHANGE THE FREQUENCY CHARACTERISTICS OF THE EARTHQUAKE ACCELERATION WAVE BY FOURIER ANALYSIS

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ABSTRACT

The earthquake acceleration time history was required a basis to determine the earthquake loading for the building structure design. For the purpose of adjusting to the soil condition and seismicity of the specific site, then the frequency characteristics of the time history need to be changed. To achieve this goal, it has been developed the computer program to change the frequency characteristics of the earthquake acceleration time history based on spectral matching analysis by the Fourier analysis. In the analysis, it was needed an actual time history and a target spectrum. Results of the study are that matching spectrums very close to target spectrums. The errors are quite small, well below as acceptable in civil engineering requirement.

Key words: frequency characteristics, time history, spectral matching, Fourier analysis.

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1. INTRODUCTION

The earthquake acceleration wave or the best known as the earthquake acceleration time history was required as a basis to determine the earthquake loading for the building structure design. For the purpose of adjusting to the soil condition and seismicity of the specific site, so that the frequency characteristics of the time history need to be changed. The frequency characteristics of a time history can be seen on its spectrum characteristics. Likewise the spectrum characteristics of a time history can be modified and adjusted in order to adhere and approximate to the other particular target spectrum by specific method, called spectral matching.

For this objectives is necessitated *i*) a target spectrum (target response spectra) of the site and *ii*) an acceleration time history of the measurement result as a basis time history. Nicolaou (1998) has brought off the study to transform the frequency characteristics of the Acceleration

Time History (ATH). Deterministically, Carlson et al. (2014) altered the frequency characteristics of the suite of 28 ground motions before being used as input to a bilinear SDOF system. Ergun and Ates (2013) transformed the frequency characteristics of the actual acceleration time histories to generate new time histories and compare the effects of near-fault ground motions on structures with far fault ground motions' effects. Wood and Hutchinson (2012) selected ground motion using a probabilistic seismic hazard analysis and altered the frequency characteristics of the ground motion to certain target spectrum. Bayati and Soltani (2016) have selected and changed the frequency characteristics of the ground motion deterministically for seismic design of RC frames against collapse. Pavel and Vacareanu (2016) were selected actual acceleration time history using a probabilistic seismic hazard analysis and transform its frequency characteristics to appropriate spectrum to generate a new time history.

Associated with altering of the frequency characteristics of ATH, in this research is made the target spectrum based on some methods. Choosing the measured acceleration time history called actual time history from the source (https://ngawest2.berkeley.edu/). For the sake of changes the frequency characteristics of the actual time history, then the computer program is developed based on Fourier analysis.

2. FOURIER SERIES

The general trigonometric form of the Fourier series for a function with period, T is,

$$x(t) = a_0 + \sum_{i=1}^{\infty} a_n \cos\omega_n t + b_n \sin\omega_n t \quad (1)$$

where a_0, a_n, b_n are Fourier coefficient.

If the Fourier coefficient a_n and b_n multiple by factors in frequency domain and the new coefficient of a_n and b_n is utilized to perform the Fourier analysis, then it will be obtained new $x(t)$ with different quantity and characteristic.

3. TARGET SPECTRUM

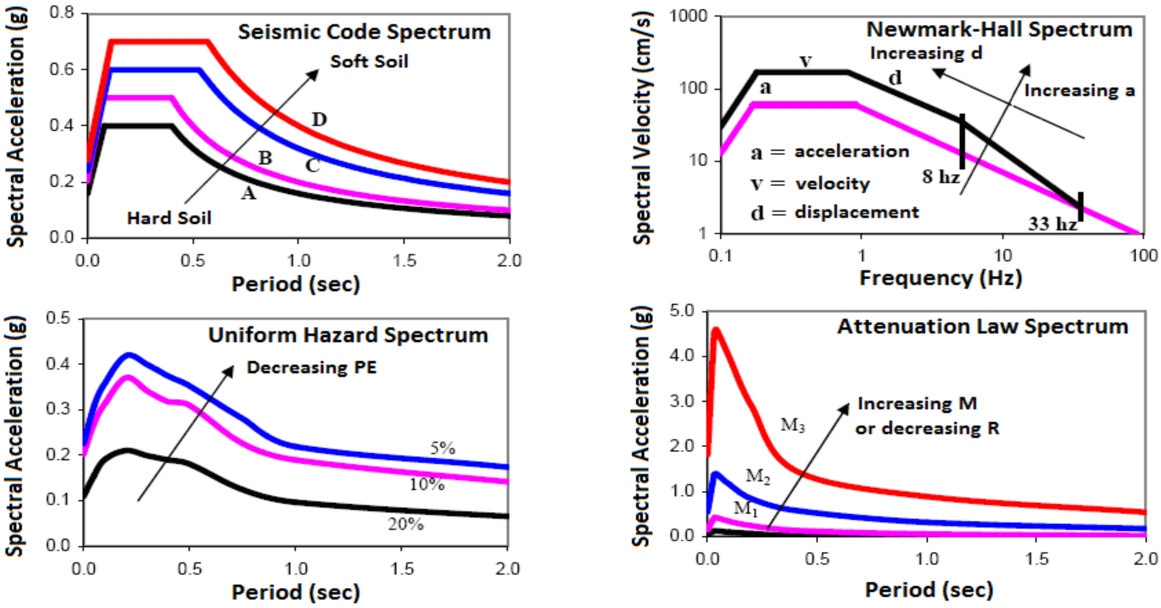

Figure 1 Response spectra for target spectrum

The response spectra can be determined based on some methods i.e. empirically or numerically. The response spectra which developed empirically are seismic code spectrum, Newmark-Hall design spectrum, uniform hazard spectrum, and attenuation law spectrum (Figure 1). The response spectra can be used as a target spectrum mainly seismic code, or uniform hazard, or attenuation law spectrum.

The numerically response spectrum generally was developed from earthquake acceleration time history of measurement result. The response spectrum can be obtained by vibration analysis use a second order linear differential equation.

4. SPECTRAL MATCHING

The spectral matching can be brought off in the two manners i.e. in the time domain and in the frequency domain. The methods can be solved with the following procedures.

4.1. Procedures matching in time domain (Nicolaou, 1998)

- Define the target acceleration response spectrum (S_a^{target})
- Compute the acceleration spectrum of the given (actual) time history (S_a^{actual})
- Calculate scaling factor (α)

The methodology considered herein minimizes an error of the square difference between matching spectrum and target spectrum, evaluated by the integral:

$$|Error| = \int_{T_1}^{T_2} \left[\alpha S_a^{actual}(T) - S_a^{target}(T)\right]^2 dT \qquad (2)$$

where T_1 and T_2 are lower and upper period of matching, respectively.

The Error will be minimums if the first derivative of Error function respect to the scaling factor α must be zero:

$$\min|Error| = \frac{d\,|Error|}{d\alpha} = 0 \qquad (3)$$

Solving of the equation (3) respect to α is:

$$\alpha = \frac{\int_{T_1}^{T_2} \left(S_a^{actusl} S_a^{target}\right) dT}{\int_{T_1}^{T_2} \left(S_a^{actusl}\right)^2 dT} \qquad (4)$$

4.2. Procedures matching in frequency domain (Nicolaou, 1998)

- Select a time history to be utilized for matching process (TH_{actual})
- Select a target spectrum (S_a^{target})
- Compute the response spectrum of the TH_{actual} to be S_a^{actual}
- Calculate the ratio between the response spectrum of the TH_{actual} and the target spectrum, $SPR(T)$

$$SPR(T) = \frac{S_a^{t\arg et}}{S_a^{actusl}} \tag{5}$$

where T is spectral period

- Introduce frequency domain, $SPR(T)$ given by

$$FILT(\omega) = SPR(\omega) \tag{6}$$

where ω is the cyclic frequency

- Calculate the Fourier coefficients $A_n(\omega)$ and $B_n(\omega)$ of actual time history using discrete Fourier analysis algorithm as $FC_{actual}(\omega)$.
- Filter the $FC_{actual}(\omega)$ by the filter $FILT(\omega)$

$$FC_{filtered}(\omega) = FILT(\omega)\, FC_{actual}(\omega) \tag{7}$$

- Generate a time history with the frequency characteristic of item-j by using inverse Fourier of $FC_{filtered}(\omega)$ to get $TH(t)$
- Calculate the average error (deviation of the response spectrum of $TH(t)$ from the target spectrum) by the Equation (8)

$$|Error|\% = 100 \frac{\sqrt{\int_{T_1}^{T_2} \left(S_a^{matching} - S_a^{t\arg et}\right)^2 dT}}{\int_{T_1}^{T_2} S_a^{actusl}\, dT} \tag{8}$$

If the error computed is acceptable within the specified tolerance limits, then $TH(t)$ is the desired time history. If the error is unacceptable then item-e to item-l are repeated.

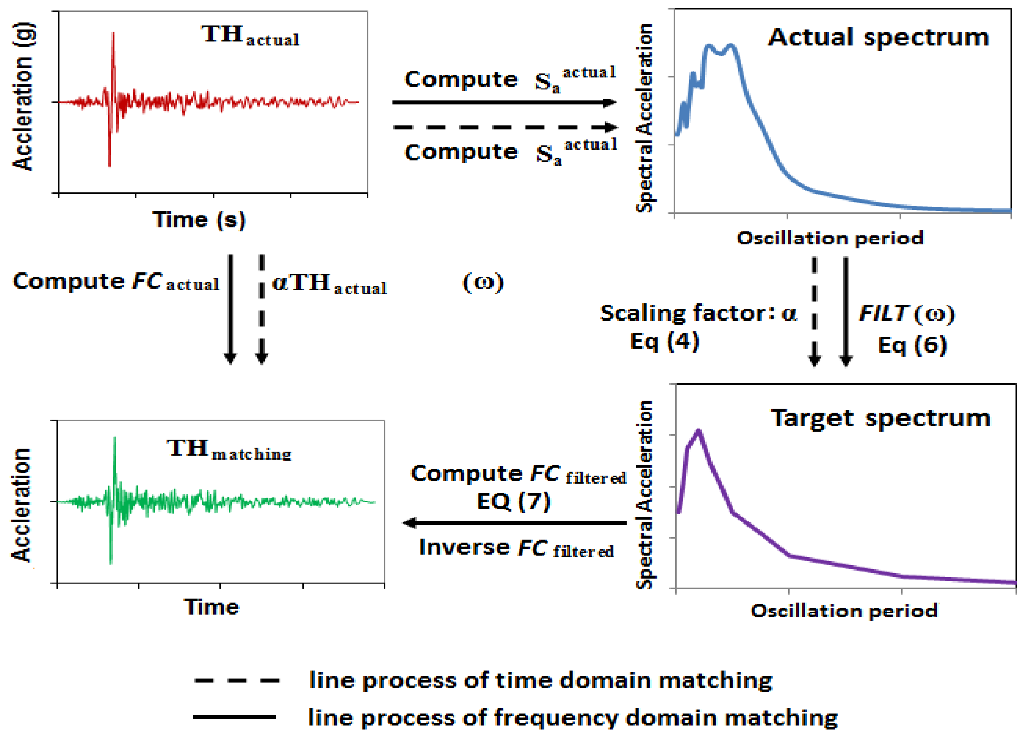

Figure 2 Methodology developed for spectral matching

The frequency domain can be combined with the time domain matching to decrease the error. In this case the result of matching in frequency domain is matched back with the time domain and directly the error automatically to be decrease. Based on the procedures was developed the computer program with fortran language and the results of matching with the program can be seen in the next paragraphs.

5. GENERATING DATA

The site for case study is taken the point 110.4130^{0}east; 7.6874^{0}south. The point is the place of the Islamic University of Indonesia (UII) Yogyakarta Indonesia. The site has minimum 15.304 km and maximum 38.35 km distance to the Opak fault (Figure 3). The fault has maximum magnitude M = 6.8 (Asrurifak, 2010). The fault has been set as a shallow crustal fault for this study.

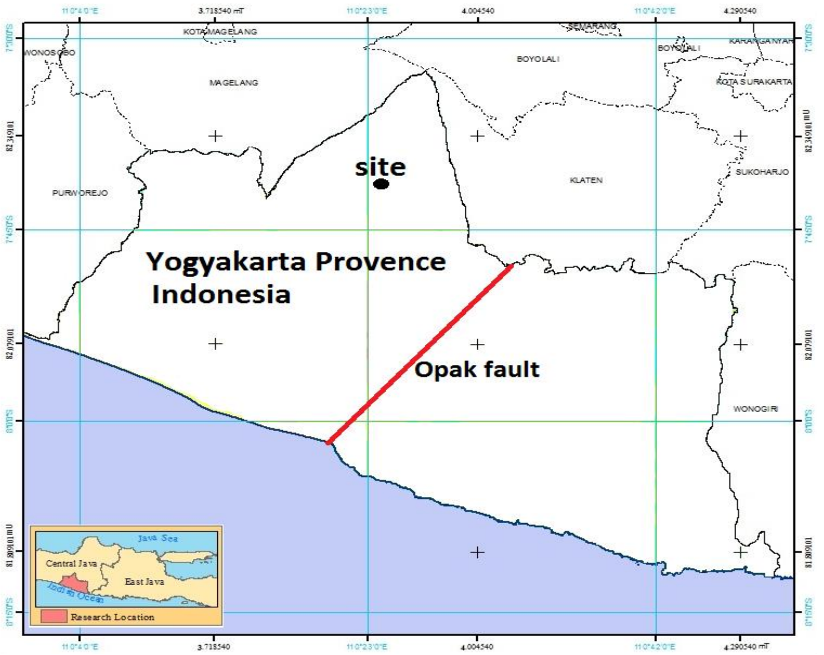

Figure 3 Sketch of Opak fault Yogyakarta Indonesia

In this research it was used the three target spectrums as mention in Figure 1, i.e. the attenuation law, uniform hazard, and seismic code spectrum. Explanation of each target spectrum is in the next paragraphs.

5.1. The attenuation law spectrum

The attenuation law spectrum calculated based on the attenuation equation that was developed by experts. In this case, the attenuation equation which utilized is Sadigh et al. (1997). It assumed that the earthquake magnitude M = 6.5, distance R = 20 km and depth H = 10 km can be occurred in the Opak fault and the earthquake can give the threat for the site. Based on the magnitude and distance it was obtained the attenuation spectral Figure 4, and the spectrum used as target spectrum for next calculation.

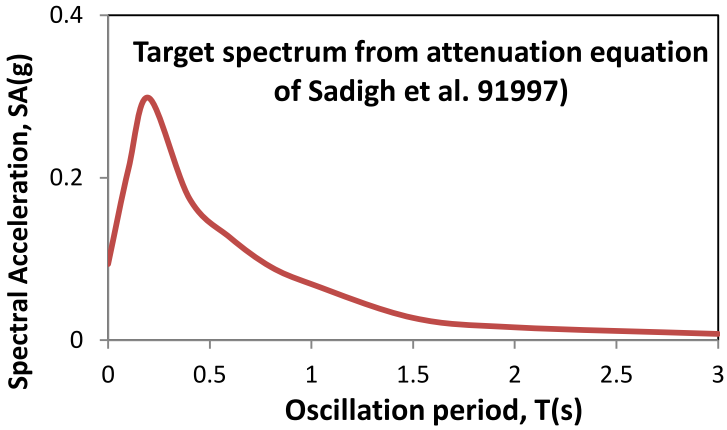

Figure 4 The attenuation response spectrum of Sadigh et al. (1997)

5.2. The uniform hazard spectrum

The uniform hazard spectrum is developed based on the Probabilistic Seismic Hazard Analysis (PSHA). The PSHA is conducted base on the point of the Islamic University of Indonesia, seismic sources vicinage of Java and source and site parameter similar to Makrup and Jamal (2016). The uniform hazard spectrum result of the analysis is in Figure 5.

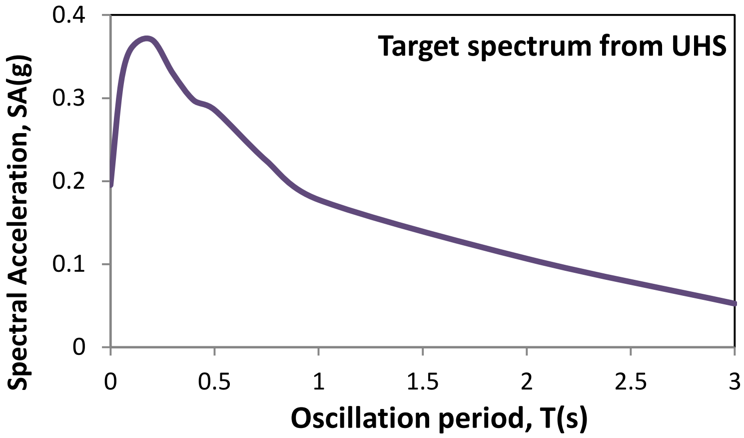

Figure 5 The uniform hazard spectrum of the point 110.4130^{0}east; 7.6874^{0}south.

5.3. The seismic code spectrum

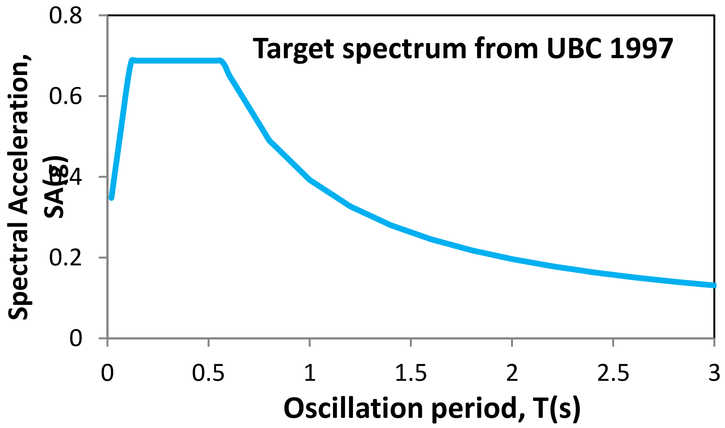

Figure 6 The UBC 1997 spectrum as target spectrum.

To obtain seismic code spectrum, in this study was employed Uniform Building Code (UBC) 1997. The spectrum developed based on Peak Ground Acceleration (PGA) = 0.1952g (see Figure 5) and site soil type D. The computation result for the spectrum is in Figure 6.

5.4. The actual time history

The earthquake acceleration time history (the actual time history) that utilized in this study is a time history of Duzce Turkey earthquake 1999 (Figure 8). The time history is utilized as a basis to conduct the spectral matching. The response spectrum of the time history is in Figure 9. The response spectrum is utilized as actual spectrum in matching process.

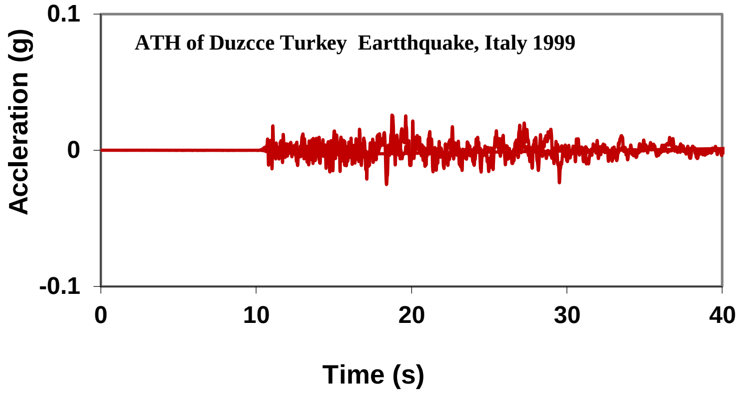

Figure 8 Time history of Duzce Turkey earthquake 1999

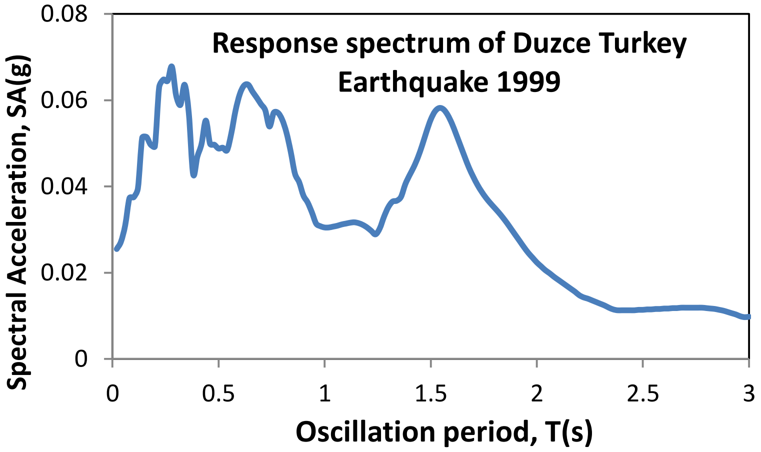

Figure 9 Response spectrum of Duzce Turkey earthquake 1999

6. RESULT

Result of the study with the spectral matching used the three target spectrums above. The results can be seen in the following figures.

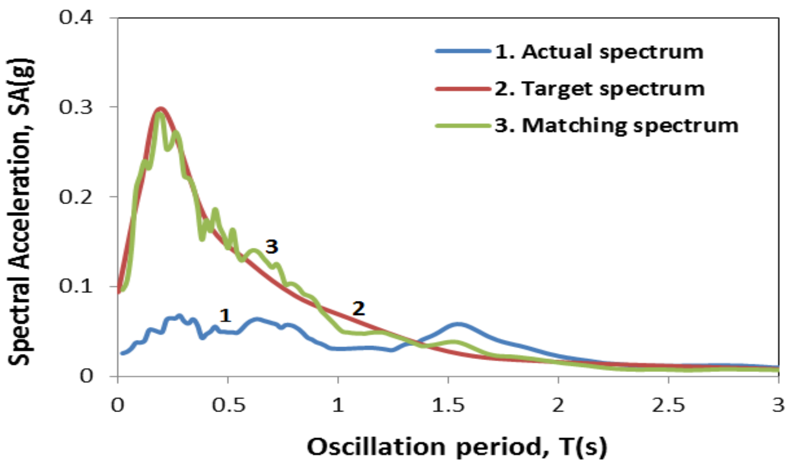

Figure 10 Spectral matching with target spectrum is the attenuation law spectrum

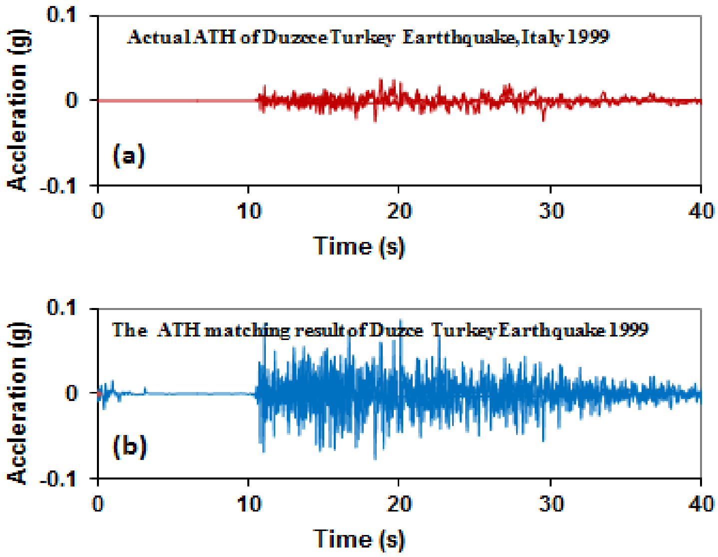

Figure 11 (a) The actual time history measurement result. (b) The matching time history which frequency characteristics agree with the attenuation law spectrum and different from frequency characteristics of actual time history.

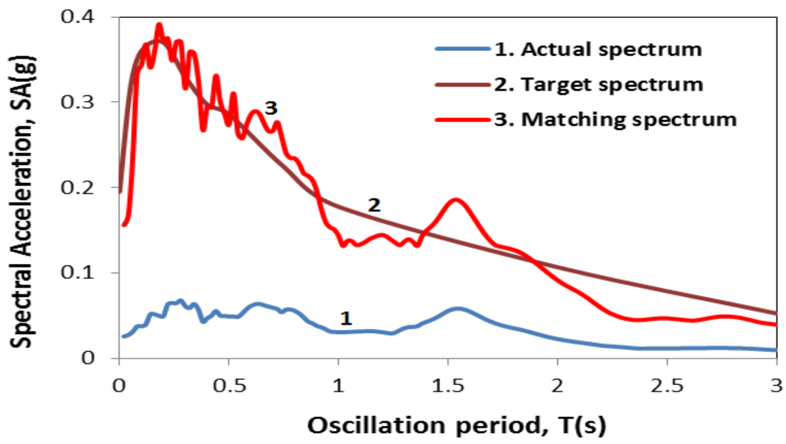

Figure 12 Spectral matching with target spectrum is the uniform hazard spectrum

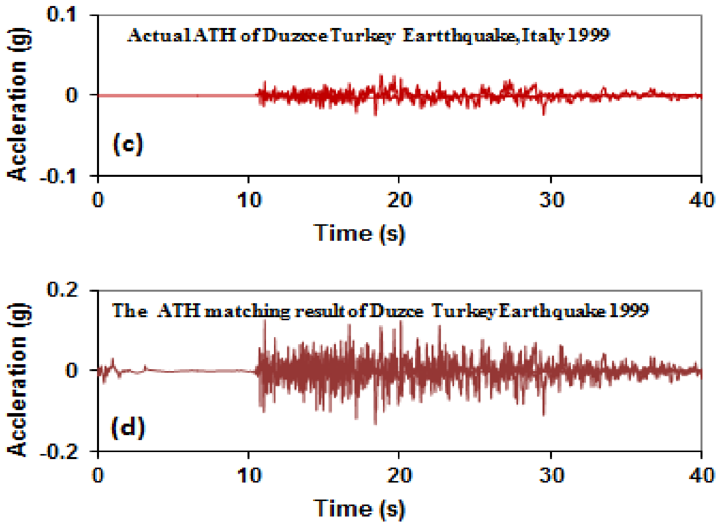

Figure 13 (c) The actual time history measurement result. (d) The matching time history which frequency characteristics agree with the uniform hazard spectrum characteristics

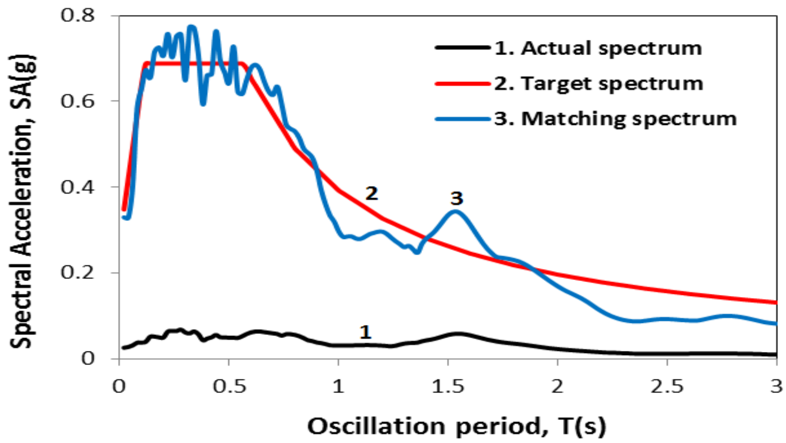

Figure 14 Spectral matching with target spectrum is the UBC 1997 spectrum

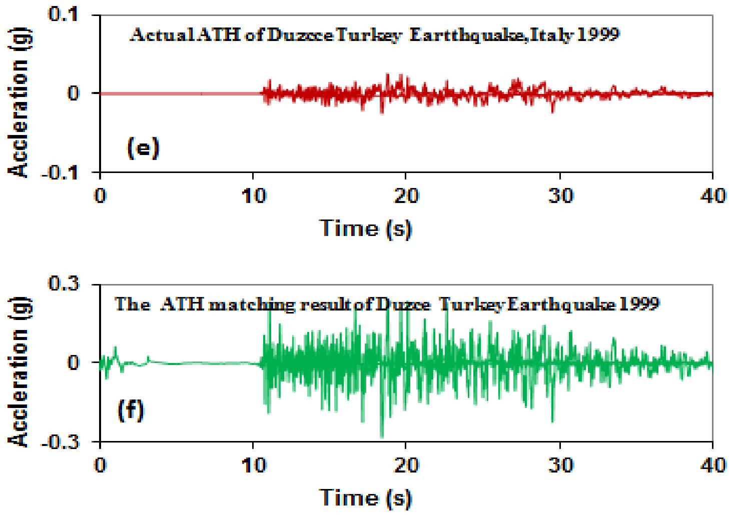

Figure 15 (c) The actual time history measurement result. (d) The matching time history which frequency characteristics agree with the seismic code spectrum characteristics

7. DISCUSSIONS

The frequency characteristics of the earthquake acceleration wave were showed by its response spectrum pattern. The Fourier analysis (the Fourier series) is the power full tool to change the frequency characteristics of the time history in order to fit to the specific target spectrum. The result of this study in Figure 10, 12, and 14 show that matching spectrums very close to target spectrums. The error of the matching spectrums to the target spectrums are 1.16%, 1.45%, and 1.28% according to the Figure 10, 12, and 13 respectively. The errors are well below the 5% as acceptable in civil engineering requirement.

8. CONCLUSIONS

This research has produced the computer program that can be utilized as a tool to change the frequency characteristics of the earthquake acceleration time history. The program outcome shows that matching spectrums very close to target spectrums. The errors are quite small, well below as acceptable in civil engineering requirement. Therefore the computer program is appropriate to be used in spectral matching analysis to generate the earthquake acceleration time history.

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REFERENCES

[1] Bayati Z, Soltani M.(2016) Ground motion selection and scaling for seismic design of RC frames against collapse. *Earthquakes and Structures*, Volume 11, Issue 3, 2016, pp.445-459.

[2] Carlson C. Pp., Zekkos D., McCormick J. P. (2014) Impact of time and frequency domain ground motion modification on the response of a SDOF system. *Earthquakes and Structures*, Volume 7, Issue 6, 2014, pp.1283-1301.

[3] Ergun M. and Ates S. (2013) Selecting and scaling ground motion time histories according to Eurocode 8 and ASCE 7-05, *Earthquakes and Structures*, Volume 5, Issue 2, 2013, pp.129-142.

[4] Makrup, L. and Jamal A. U., (2016). The Earthquake Ground Motion and Response Spectra Design for Sleman, Yogyakarta, Indonesia with Probabilistic Seismic Hazard Analysis and Spectral Matching in Time Domain, *American Journal of Civil Engineering*, 4(6): 298-305.

[5] Nicolaou.A.S. (1998), *A GIS Platform for Earthquake Risk Analysis*. A dissertation submitted to the Faculty of the Graduate School of State University of New York at Buffalo USA in partial fulfillment of the requirement for the degree of Doctor of Philosophy, August.

[6] Pavel F., Vacareanu R. (2016) Scaling of ground motions from Vrancea (Romania) earthquakes. *Earthquakes and Structures*, Volume 11, Issue 3, 2016, pp.505-516.

[7] Sadigh K. et. al. (1997) Attenuation Relationships for shallow Crustal Earthquake Based on California Strong Motion Data, *Seismological Research Letters*, Volume 68 Januari/Pebruary 1997, Seismological Society of America.

[8] Wood, R.L., Hutchinson, T.C. (2012) Effects of ground motion scaling on nonlinear higher mode building response, *Earthquakes and Structures*, Volume 3, Issue 6, 2012, pp.869-887.

[9] Rajan Kumar, M.K. Mishra, S.K. Singh and Arbind Kumar, Fourier Transform Infrared Spectrophotometry Studies of Jatropha Biodiesel and its Blends for Engine Performance. International Journal of Mechanical Engineering and Technology, 7(5), 2016, pp. 330–335.

[10] Priyanka Chauhan and Girish Chandra Thakur, "Efficient Way of Image Encryption Using Generalized Weighted Fractional Fourier Transform with Double Random Phase Encoding" International Journal of Advanced Research in Engineering & Technology (IJARET), Volume 5, Issue 6, 2014, pp. 45 – 52

[11] Siddharth Narayanan and P K Thirivikraman, Image Similarity Using Fourier Transform. International journal of Computer Engineering & Technology (IJCET), 6(2), 2015, pp. 29–37.