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Simplification of Earthquake Accelerograms for Quick Time History Analyses for MDOF Systems by Using Their Modified Inverse Fourier Transforms

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SUMMARY

A method is introduced for simplification of accelerograms based on their modified Inverse Fourier Transform (IFT), which makes possible using much larger time steps in Time History Analysis (THA). In the proposed method the Fourier Transform of the accelerogram is calculated, and then the corresponding IFTis calculated using a relatively large time step, usually 5 to 10 times of the original accelerogram's time step. The simplified record is very similar to the original one, but has much larger time steps. Obviously, the required time for THA by using this simplified accelerogram is remarkably less. To show the efficiency of the proposed method a set of multi-story two-dimensional frames is considered and analyzed by the original records and their simplified versions with large time steps. Resultsshow that using the simplified accelerograms leads to only 5-10% error in maximum responses, while decreases the required calculation time up to 10 times.

Keywords: Fourier and Inverse Fourier Transforms, Larger time steps, Multi-story two-dimensional frames

1. INTRODUCTION

Seismic design and Dynamic Analysis are main objective in many research [5],[7] and investigating the effects of combined earthquake and dead load on lateral load resistance building systemsis very common inResearches and codes [6]. Inseismic design and evaluation of many kinds of structures, including irregular building systems, there are several cases in which the simplified seismic analysis procedures suggested by seismic design codes, are not usable. Irregular buildings, buildings with more than 15 stories (according to most of codes), and many special structures are some of these cases. In such cases most codes recommend time history analysis (THA) as the most appropriate analysis procedure. However, THA is usually very time-consuming and therefore costly, basically, because of the very small size of the time step used in digitization of accelerograms. On this basis, if the time history analysis can be performed by relatively larger time steps, without losing much precision, it will be very helpful. Using simplified accelerograms, as discussed by Wang [1] in 1975 and Wang and Goel [2] in 1977 is an approach for this purpose. In these two works the real accelerogram has been condensed into a four-pulse model by a minimization method, using rectangular pulses. Creating the possibility of using larger time steps, by some techniques as proposed by Soroushian [3] in 2008, is another approach proposed for this purpose. Simplification of digitized accelerograms, however, can be done by some other means such as Fourier and Inverse Fourier Transforms, so that the simplified accelerogram can have much larger time steps.

In this paper a method is introduced for simplification of accelerograms based on the modification of their Fourier analyses. For this purpose, at first the Fourier Spectrum of the accelerogram is calculated, by a computer program,

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developed by the authors. Then, by using the developed computer program the corresponding Inverse Fourier Transform is calculated, using a relatively large time step, depending on the period of the highest used frequency (which is usually 5 to 10 times larger than the original accelerogram's time step) to create the simplified accelerogram. The use of accelerograms, simplified by the proposed method, in case of linear SDOF systems, and the good precision of the calculated responses have been presented in a previous paper of the authors, Faroughi and Hosseini, [4], in 2011. The details of this technique are described in the following section of the paper, and its efficiency in reducing the required time for the cases of THA of 3-, 5-, 7-, and 9-story 2-dimensional frames is shown by some numerical examples.

2. ACCELEROGRAM SIMPLIFICATION TECHNIQUE AND SAMPLE RESULTS

The proposed simplification technique for quick Time History Analysis (THA) of buildings systems is based on some modifications in the Fourier Transform (FT) and Inverse Fourier Transform (IFT). The simplification technique simply consists of calculating FT of thedigitized accelerogram and then calculating its IFTusing time step size much larger than the one used in digitization of the original accelerogram. For performing this modification, a computer program has been developed by the authors, which is compatible with Microsoft Office program. In this computer program at first the FTof the ground acceleration time history, $a_g(t)$, is calculated by:

$$F(\omega) = \int_0^{\tau_0} a_g(t) e^{-i\omega t}\, dt \tag{1}$$

Where •$_0$ is the duration of the record. Regarding that F(ω) has a real part and an imaginary part as:

$$\mathrm{C}(\omega) = \int_0^{T_0} a_g(t) \cos\omega\, t dt \tag{2}$$

$$\mathrm{S}(\omega) = \int_0^{T_0} a_g(t) \sin\omega\, t dt \tag{3}$$

The Fourier amplitude or spectral value can be calculated as:

$$FAS(\omega) = \sqrt{C^2(\omega) + S^2(\omega)} \tag{4}$$

Then, any desired number of peaks can be selected for modification of Inverse Fourier Transform of the acceleration record, as shown in Figure 1.

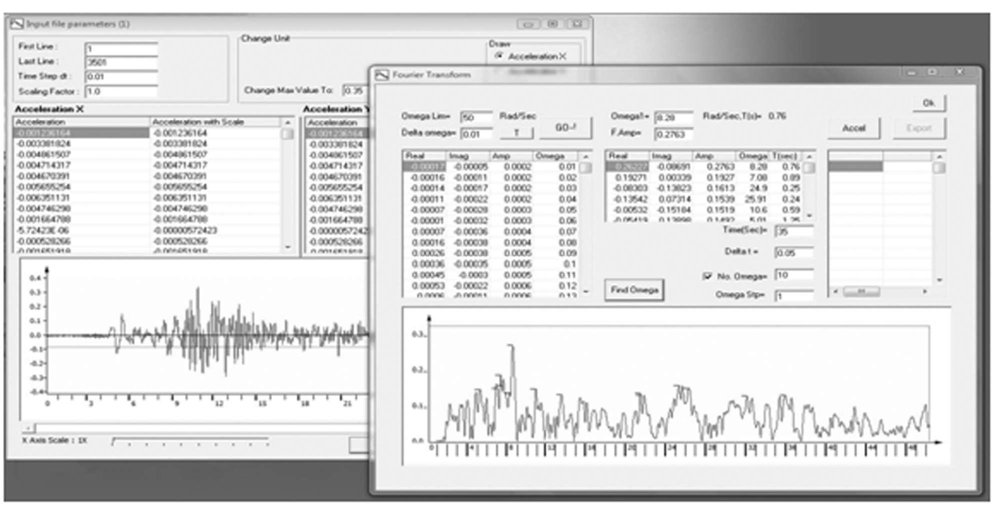

Figure 1: A sample screen view of the computer program for simplification of digitized accelerograms in which the acceleration history of Tabas, Iran, earthquake of 1978 and its Fourier Transform can bee seen in red

The acceleration time history shown in Figure 1, of which the Fourier Transform has been also shown in the figure, is related to one of the recorded accelerograms of Tabas, Iran, earthquake of 1978, which has been digitized with a time step size of 0.01 sec. After selecting the desired number of peaks, which itself depends on the number of peaks which are close to the dominant natural frequencies of the structural system, an appropriate frequency band is considered for inclusion of frequencies around the peaks in the modified Inverse Fourier Transform of the record. Then, by choosing a larger time step such as 0.05 sec the modified Inverse Fourier Transform of the record is calculated, as shown in Figure 2.

Comparing the time history shown in Figures 2 with the original one shown in Figure 1, it can be observed that the reproduced record is very different from the original one. To find out whether this dissimilarity has any significant effect on the response values the response of a SDOF system with natural period of 0.3 sec have been calculated by both records, the results of which are shown in Figure 3.

It can be seen in Figure 3 that the two responses are not in good agreement. In fact, there is a difference of approximately 25 percent between the two peak responses and the instants of the peak responses are not the same. These differences can be due to either the deletion of some parts of the Fourier Spectrum or choosing a large time step for calculation of the Inverse Fourier Transform. To see which one of these two can be the main reason, it was decided to use the full Fourier Spectrum, and use just a large time step for calculating the Inverse Fourier Transform. The results of these calculations, using a time step size of 0.05 sec, which is ten times of the time step size of the original record (0.005 sec), can be seen in Figure 4, which relates to one of the accelerograms of Chi-Chi, Taiwan, earthquake of 1999.

In Figure 4, it can be seen that the two records have very similar patterns, however, the simplified record has lower values. The reason behind this reduction is the use of larger time step size. However, the simplified record can be easily corrected by applying an appropriate scaling factor. To see whether the simplified record results in

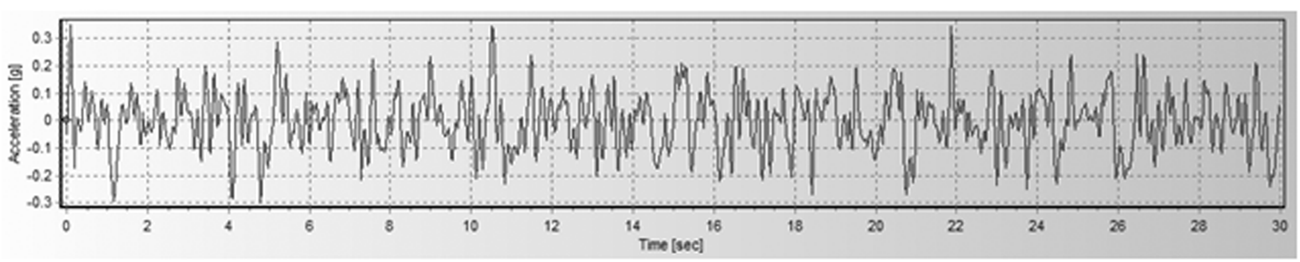

Figure 2: Simplified record of Tabas earthquake with larger time steps

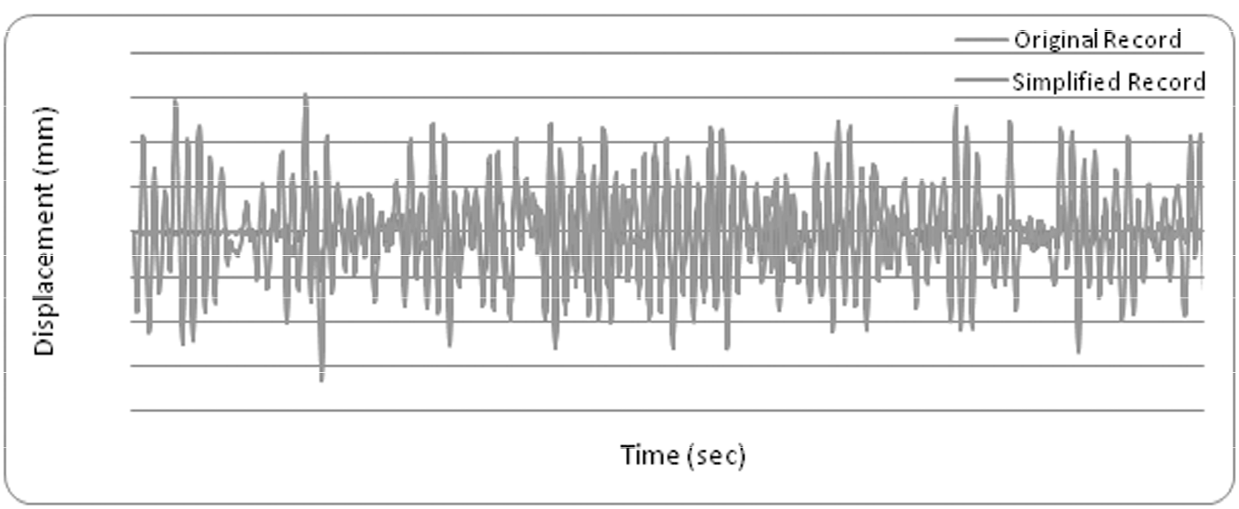

Figure 3: Response time histories of a SDOF system with natural period of 0.3 sec to original and simplified records of Tabas earthquake

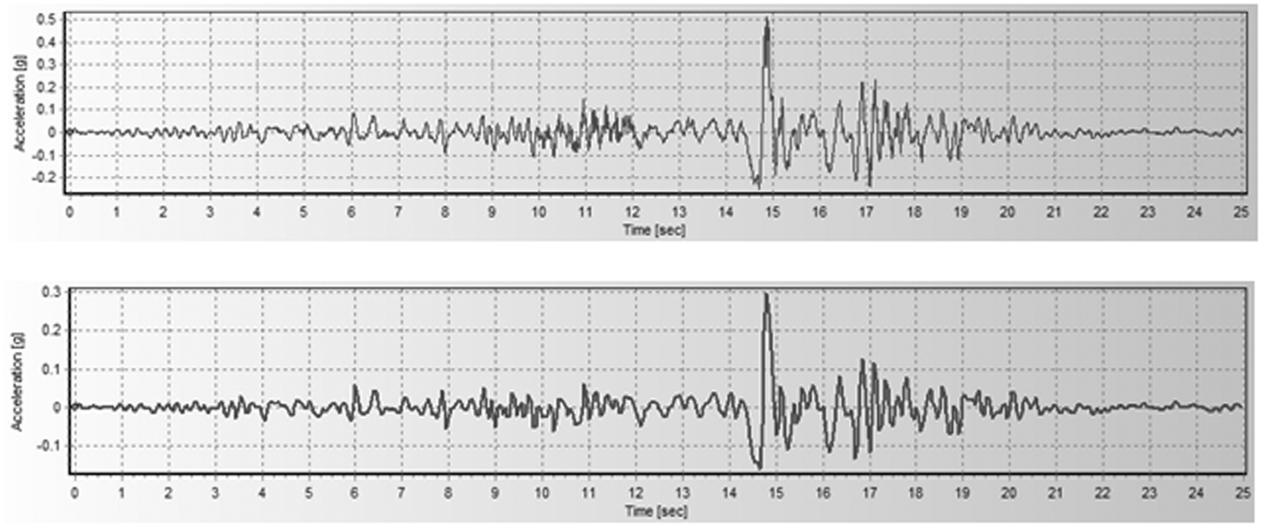

Figure 4: The original (up) and the simplified (down) records of Chi-Chi, Taiwan, earthquake

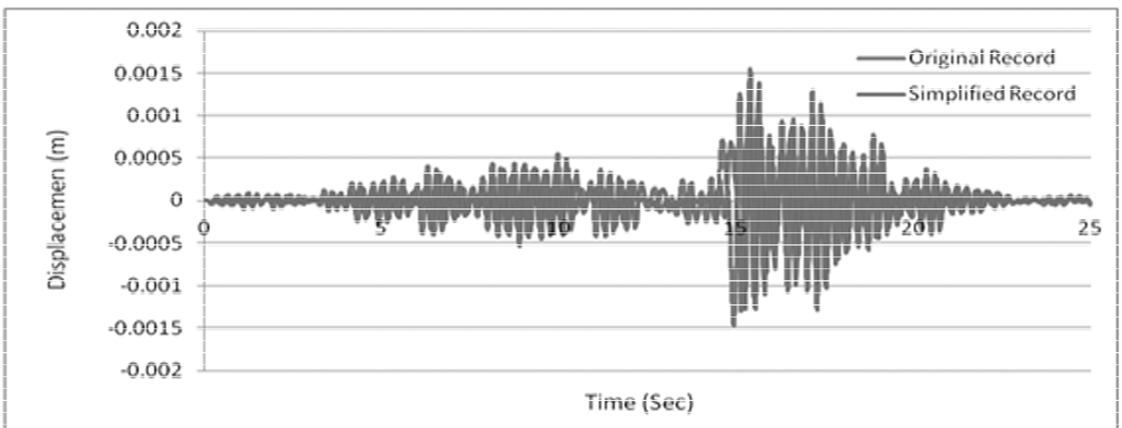

Figure 5: Displacement response history of 3-story 2-dimensional frame, having natural period of 0.3 sec calculated by both original and simplified records of Chi-Chi earthquake

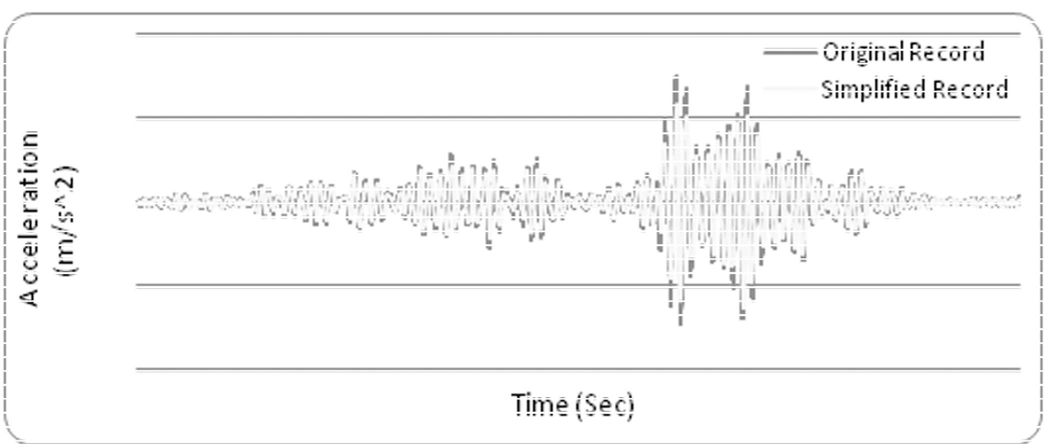

Figure 6. Acceleration response history of 3-story 2-dimensional frame, having natural period of 0.3 sec calculated by both original and simplified records of Chi-Chi earthquake

acceptable response values, the displacement and acceleration responses of some MDOF systems, (3-, 5-, 7-, and 9-story 2-dimensional frames) having, respectively, natural periods of 0.3, 0.5, 0.7, and 0.9 sec were calculated by both original and simplified records of Chi-Chi earthquake. The results related to the system with natural periods of 0.3 and 0.5 sec are shown respectively in Figures 5 and 6.

The good agreement of response histories, obtained by the original and the simplified records, can be observed in Figures 5 and 6. However, it is seen in these figures that the response values obtained by the simplified record are a little underestimated. That is because of that fact that during the integration with larger time steps for obtaining the IFT some frequencies may be lost. A small time shift is also observed in case of the simplified displacement time history, but surprisingly, it is not observed in the simplified acceleration time history. The reason behind this shift is not clear to the authors, but it may be related to numerical integration errors. Figures 7 and 8 show the response histories of the 5-story frame having a natural period of 0.5 sec obtained by the original and simplified records of Chi-Chi earthquake.

Looking at Figures 7 and 8 and comparing them with Figures 5 and 6, a better agreement is observed between the response values obtained by the original and simplified accelerograms for the MDOF system with natural period of 0.5 sec than those of the system with natural period of 0.3 sec. This indicates that there is a correlation between the precision of the response values and the natural period of the system. There are more results of this type for systems with different natural periods, obtained by employing the accelerograms of several earthquakes with various frequency contents from low to high, but can not be presented here due to the lack of space.

To make sure that the agreement exists in the whole frequency range of the earthquakes for acceleration responses as well, the Fourier amplitude, the pseudo velocity and also the pseudo acceleration spectra of both original and simplified records were calculated. Samples of these spectra are shown in Figure 9, which are related to accelerogram of Chi-Chi earthquake and its simplified record using a time step size of 0.05 sec, which is 10 times of the time step size of the original record.

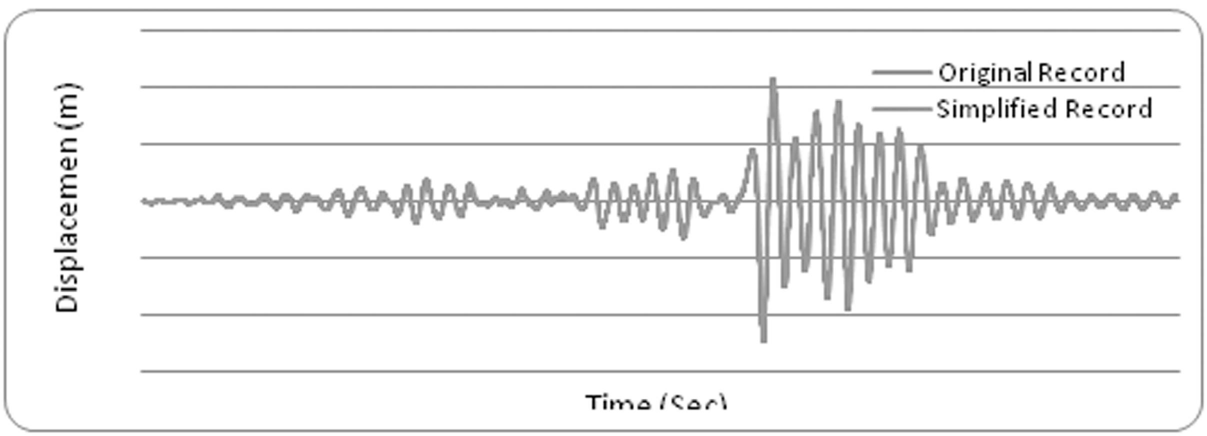

Figure 7: Displacement response history of 5-story 2-dimensional frame, having natural period of 0.5 sec calculated by both original and simplified records of Chi-Chi earthquake

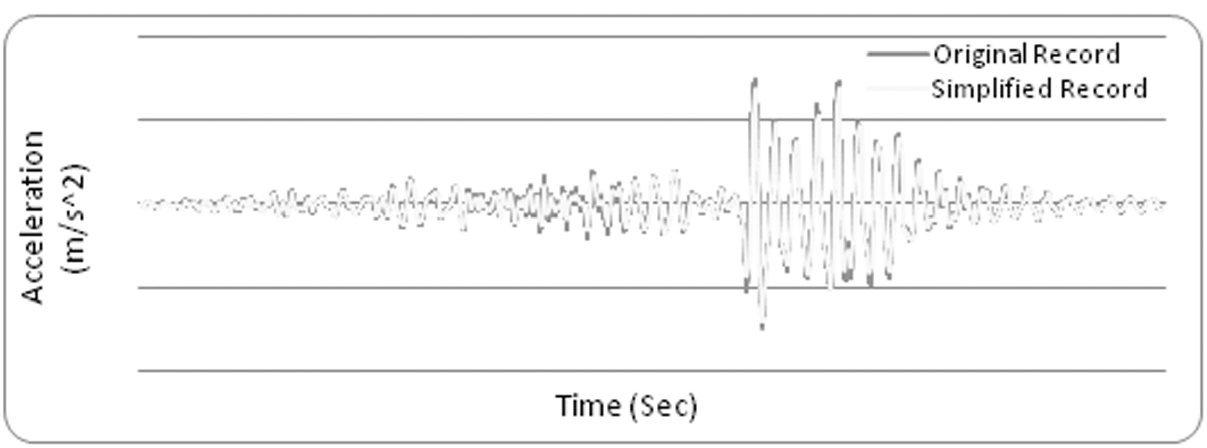

Figure 8: Acceleration response history of 5-story 2-dimensional frame, having natural period of 0.5 sec calculated by both original and simplified records of Chi-Chi earthquake

Looking at the Figure 9 one can see good match of the Fourier amplitude spectra of the original and the simplified records. Just in the high frequency range a little difference is observed which, considering the nature of the proposed simplification technique, is quite expectable. Obviously, using smaller time intervals in calculation of IFT lead to better matches of the two spectra. Figures 10 and 11 show, respectively, the pseudo velocity and acceleration spectra of the original as well as the simplified records of Chi-Chi earthquake.

It can be seen in Figures 10 and 11 that a very good agreement exists between the two pseudo velocity and pseudo acceleration spectra in almost the whole period range. As expected, in case of pseudo acceleration spectra the agreement is a little weak in the range of very lower periods, or higher frequencies.

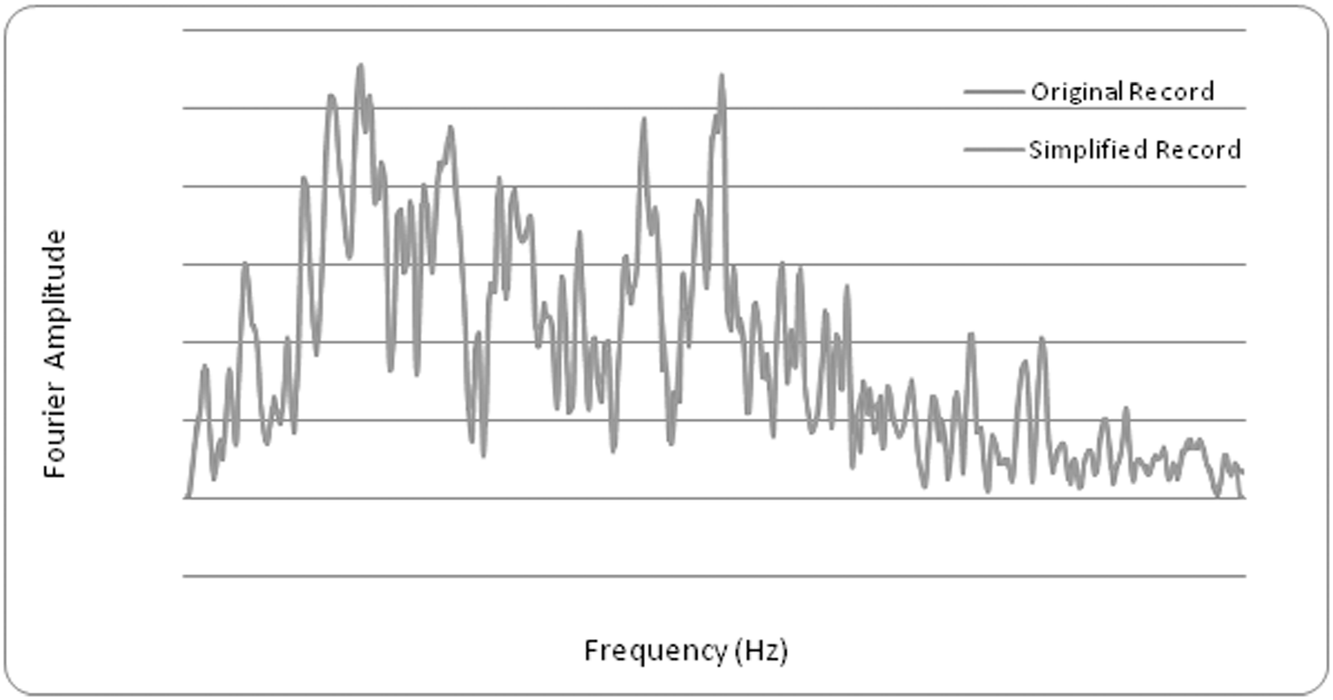

Figure 9: Fourier amplitude spectra of the considered accelerogram of Chi-Chi earthquake calculated by both original and simplified records, using a time step size of 0.05 sec (10 times of the original record)

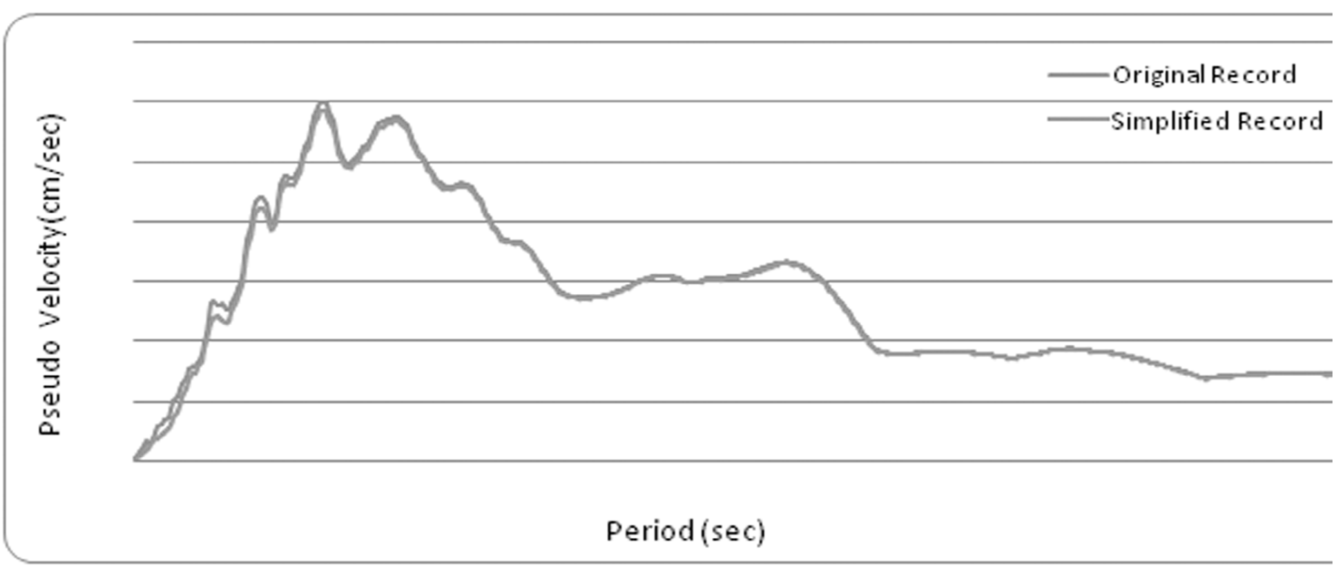

Figure 10: Pseudo velocity spectra of Chi-Chi earthquake calculated by both original and simplified records, using a time step size of 0.05 sec (10 times of the original record)

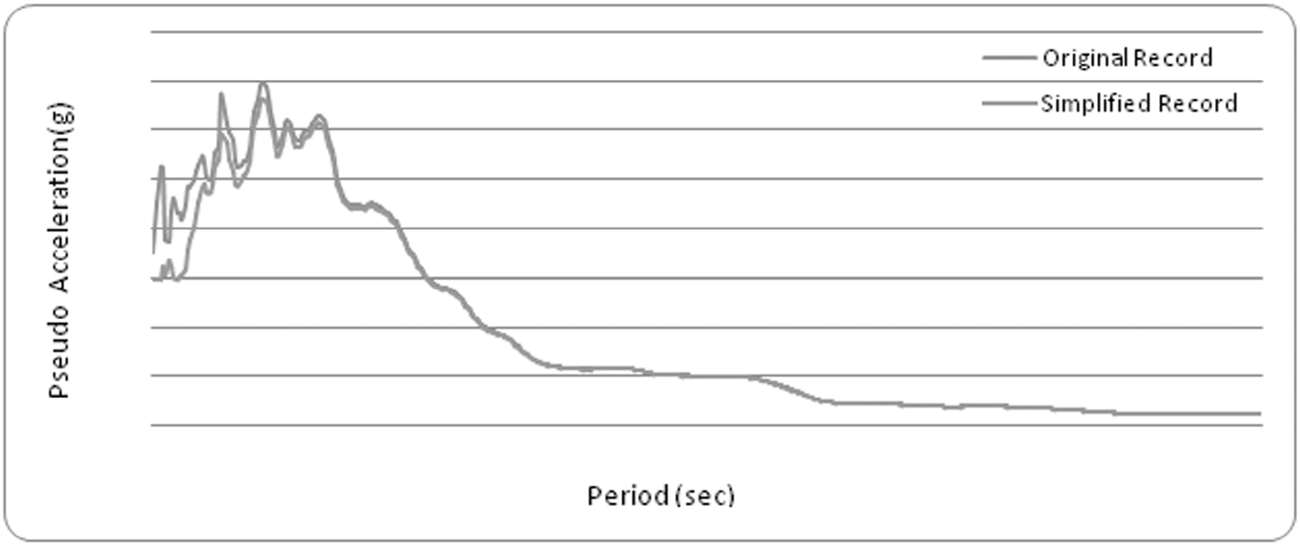

Figure 11: Pseudo acceleration spectra of Chi-Chi earthquake calculated by both original and simplified records, using a time step size of 0.05 sec (10 times of the original record)

3. CONCLUSIONS

Numerical results show that simplification of records by reproducing their Inverse Fourier Transform using a time step size of 5 to 10 times of that of the original records leads to only 5-10% error in the maximum values of displacement and acceleration responses, depending on the natural period of the structure and the features of the used records, while decreases the required response calculation time up to 10 times. With regard to response spectra, the simplified records leads to some reduction of the spectral acceleration values in lower period values, however the pseudo velocities of the original and the simplified records are in good agreement in the whole period range. Based on these results, it can be claimed that the proposed simplification technique is quite effective in reducing the computation time and cost of time history analyses.

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