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Continuous Wavelet and Fourier Transform Methods for the Evaluation of the Properties of Critical Excitation

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ABSTRACT: A designer needs to design a structure with the aim of obtaining the maximum possible load expected for the structure during its lifetime. In this paper, considering the information obtained from the earthquakes, the critical earthquakes were computed for a shear frame building equipped with a belt truss system and subjected to two constraint scenarios. For this purpose, a nonlinear optimization problem has been solved in which the objective function was the maximization of the roof displacement. In the first constraint scenario, the computed critical earthquake was known as the first state critical earthquake. In addition, for the second constraint scenario, the earthquake was named as the second state critical earthquake. In the first scenario, the energy, the duration of strong ground motion, and peak ground acceleration were considered as the constraints, while in the second scenario, the upper bound Fourier spectrum was added to these constraints. Finally, the properties of the initial and critical earthquakes were investigated using the Fourier analysis method and continuous wavelet transform. The numerical results showed that the Fourier spectrum of the first critical earthquake was 6.86 times higher than the maximum values for the same parameter in case of other earthquakes at a frequency near the first natural frequency of the structure. Also, using the time-frequency curve, it was shown that duration of the strong ground motion of all earthquake places within the dominant duration of the frequencies of the same earthquake was more than 10 sec.

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1. INTRODUCTION

It is important to consider the variability of earthquake characteristics during past earthquakes due to the necessity of designing structures under earthquake load. Codes and design guidelines are usually created with probabilistic insight, taking into account the knowledge obtained from observations of past earthquakes. However, uncertainties in earthquake events, fault rupture mechanisms, wave propagation mechanisms, earthquake properties, and etc. cause problems in defining an acceptable earthquake for the design of important structures considering the point that such structures should not be damaged under severe earthquakes [1-4]. Kamgar and Rahgozar studied the problem of seismic design of structures subjected to a critical earthquake [5]. In other research, Kamgar *et al.* studied the problem of designing active controllers [6] and passive tuned mass dampers [7] subjected to a critical earthquake.

Historically, the wavelet transform is a method whose mathematical foundations go back to the theory of Joseph Fourier in the nineteenth century. In fact, by introducing his theory of frequency analysis, Fourier took a fundamental step in analyzing the signals. Alfred Harr first used the term wavelet in 1909. Recently, researchers studied the engineering problems using the discrete wavelet transform.

In this paper, the critical excitations for a twenty-story shear building equipped with a belt-truss system are calculated. Then, using the Fourier transform as well as the continuous wavelet transform, the properties of the calculated critical and initial earthquakes are studied.

2. THE CRITICAL EXCITATION METHOD FOR MULTI DEGREE OF FREEDOM SYSTEM

This section describes the method of critical earthquake. For this purpose, the acceleration of the earth's motion is expressed as the product of the Fourier series and an envelope function ($e(t) = A_0(e^{-\alpha_1 t} - e^{-\alpha_2 t}) \quad \alpha_2 > \alpha_1$) as follows:

$$\ddot{u}_g(t) = A_0(e^{-\alpha_1 t} - e^{-\alpha_2 t})\sum_{i=1}^{N_f} R_i \cos(\omega_i t - \phi_i) \tag{1}$$

where R_i and ϕ_i show the amplitude and phase angle,

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respectively. In addition, $\omega_i \quad i = 1, 2, ..., N_f$ are frequencies that represent the frequency content of the earth's motion.

3.FOURIER AND CONTINUOUS WAVELET TRANSFORMS

Fourier transform is a tool that uses sine and cosine functions as basic functions to derive the frequency spectrum of the input waves, and is defined by the following formula:

$$F(\omega) = \int_{-\infty}^{\infty} x(t)e^{-j\omega t}dt \quad , \quad \omega = 2\pi f \qquad (2)$$

Also, the continuous wavelet transform is similar to the Fourier transform defined by the following formula:

$$X_{WT}(\tau, s) = \frac{1}{\sqrt{|s|}}\int_{-\infty}^{\infty} x(t)\psi^*\left(\frac{t-\tau}{s}\right)dt \qquad (3)$$

where $X_{WT}(\tau, s)$ is a function of τ (wavelet transform) and s (scale parameters). The mother wavelet is also represented by parameter ψ and * represents the complex conjugate used in wavelet conversion.

4. NUMERICAL EXAMPLE

In this section, a set of 18 accelerations is selected based on Chandler's classification and in accordance with 2800 Iranian code. Then, a twenty-story shear building used in the reference [6] is selected. Finally, critical earthquakes are calculated. Fig. 1 shows the critical earthquakes calculated for various constraint scenarios.

Now, the use of continuous wavelet transforms for the initial and critical earthquakes indicate that the duration of strong ground motion and the time of dominant frequency (a time range that most frequencies occur in it) occur approximately over a period of time for all initial and critical earthquakes (e.g. see Fig. 2.)

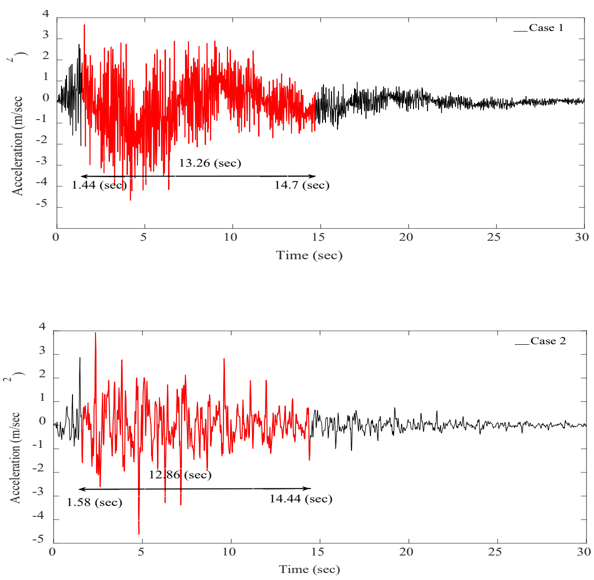

Fig. 1. The time history of acceleration for the computed critical earthquakes based on considered scenarios.

Also, using the Fourier transform, the first five frequencies of all earthquakes (e.g. for the San Fernando earthquake) are calculated and compared (see Fig. 3).

It should be noted that for the San Fernando earthquake (component N69W) where the maximum roof displacement is 0.18 times of the first critical earthquake and 0.53 times of the second critical earthquake, the first five frequencies are 2.152, 1.828, 2.168, 1.168 and 1.845 Hz. Therefore, it seems that the maximum or minimum values of the first five frequencies for the earthquake does not have any important

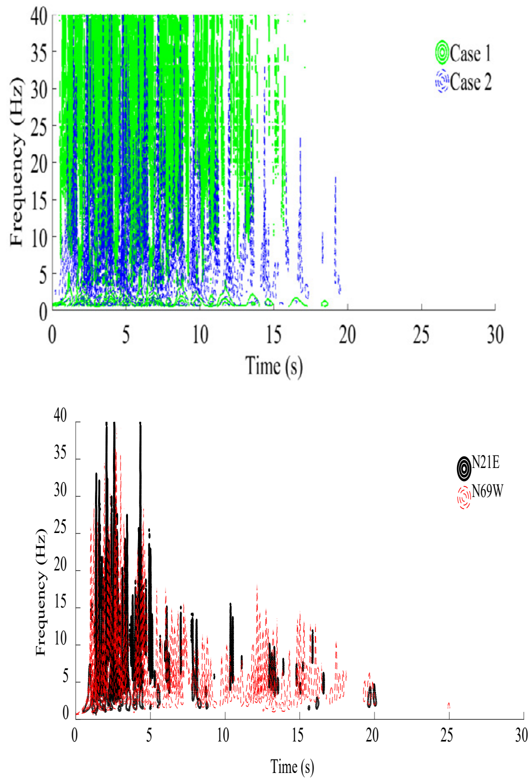

Fig. 2. Time of dominant frequency for the critical and San Fernando earthquakes using the continuous wavelet transform

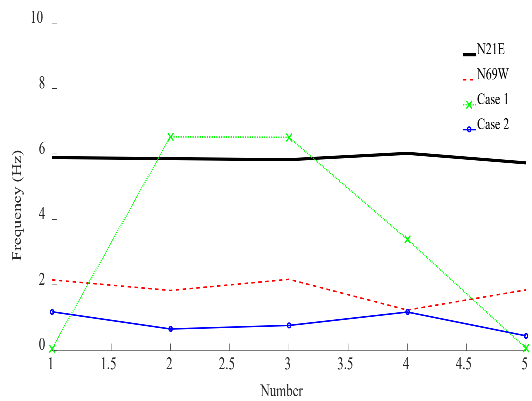

Fig. 3. A comparison between the first five frequencies for the critical and San Fernando earthquakes.

effect on the earthquake's criticality.

5. CONCLUSIONS

In this paper, critical earthquakes for a twenty-story shear building were calculated based on two constraint scenarios. Then, their properties were studied using continuous wavelet transform and Fourier transform. The results show that the values of the first five frequencies of the first and second critical earthquakes are not always lower or higher than those of the selected earthquakes. This indicates that the maximum or minimum values for the first five frequencies of the earthquake does not have any important effect and therefore it is possible not to consider this earthquake as a critical one. It is also clear from the obtained results using continuous wavelet transform as well as the Trifunac and Brady methods that in all initial and critical earthquakes, the duration of strong ground motion and the time of dominant frequency occur approximately at the same time interval.

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