HHT based structural characteristics consistency analysis under two different small recordings

Fei Wang [a, *], Xiandong Kang [b]

Beijing Earthquake Agency, Beijing 100080, China

[a]wangfei@bjseis.gov.cn, [b]kangxd@ bjseis.gov.cn

*Corresponding author

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Abstract: Hilbert-Huang transform is introduced to analyze the response recordings under two earthquakes with different epicenter distances. The intrinsic mode functions are extracted and the components with diverse frequencies are identified. The components extracted are well consistent with the original signals in frequency. The analysis indicates the HHT method is an effective way to identify the dynamic characteristics. Based on the analysis results, the structural characteristics consistence is carried out for two earthquake recordings. The amplitude differences in frequency domain are noteworthy with great input energies. However, the normalized predominant frequencies are well consistent. The frequency contents are also comparable in target frequency band. The favorable consistency highlights the effectiveness of HHT application.

1. Introduction

Structural earthquake response observation is an important part for strong motion observation. It helps to provide useful information on building response characteristics [1]. Structural response recorded during earthquake can be used equivalently as prototype testing [2]. Engineers developed different method to identify structural dynamic characteristics. Thereinto, Fast Fourier transform (FFT) and wavelet transform have been proposed for system identification in structural health monitoring and diagnosis. However, they are not suitable to analyze nonlinear process and non-stationary process [3-4]. The method of Hilbert-Huang transform (HHT) has been applied to analyze signals in the frequency-time domain. Empirical Mode Decomposition (EMD) and Hilbert transform are used to bring about HHT. EMD is the critical part in HHT and plays the significant role in data analysis. This method has already been proved better than FFT and wavelet analysis [5-6]. Furthermore, HHT method is applicable to process non-stationary time series. It is widely used in earthquake recording processing and satisfies several requirements in structural dynamics. HHT is introduced to analyze dynamic characteristics based on the structural seismic response recordings. Consistency analysis is also carried out to determine the inherent characteristics under different earthquakes.

2. Building Profile and Earthquake Recordings

The building is frame-shear wall structure and it is 33.0 meters high with 8 stories and 2 basements. An intense seismic response array was instrumented in the building with 33 sensors on basement 2, 1st floor, 3rd floor, 6th floor and the roof. Five 3-channel sensors are installed on the geometrical center and six 3-channel sensors are on the two ends of the building. A 3-channel seismometer was deployed in a 100-meter borehole. Sensor layout is demonstrated in Fig. 1. Red arrows represent the sensor and the monitoring direction. Several small earthquakes were recorded including the earthquake occurred in Yongqing County with magnitude 4.3 (EQ1) and the earthquake at the border of Baodi District, Tianjin and Yutian County with magnitude 4.0 (EQ2).

The EQ1 occurred 60 kilometers away from the building with bigger amplitudes. While the epicenter distance for EQ2 was approximately180 kilometers and the amplitudes of the recordings are much smaller. The two recordings of the building were corrected and the waveforms in North-south direction are shown in Fig.2. The peak acceleration for EQ1 is 9.0 cm/s2 and 0.20 cm/s2 for EQ1. The amplitudes of the recordings on the roof for these two earthquakes are distinct and analyses are carried forward by selecting the roof recordings.

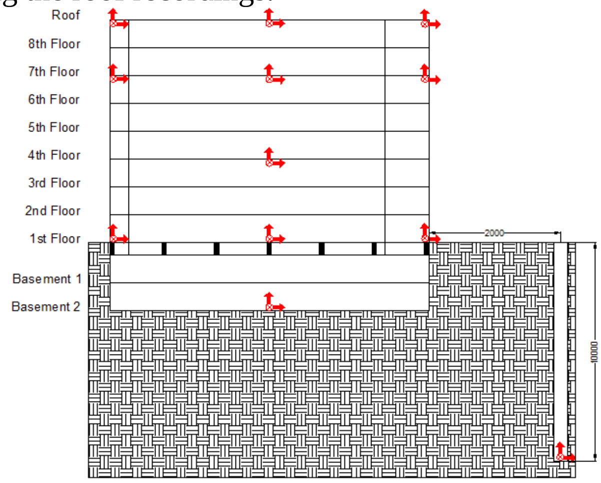

Fig. 1 Layout of 36 sensors instrumented in the building.

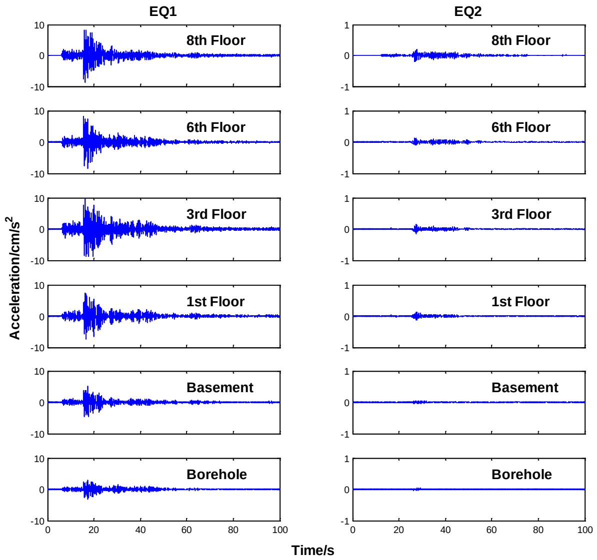

Fig. 2 North-south direction earthquake waveforms for EQ1 and EQ2

3. HHT Based Consistency Analysis

Take the roof data for EQ1 for example using HHT method. EMD is applied and the first 5 intrinsic mode functions (IMFs) are decomposed. They are nominated from IMF_1 to IMF_5 as demonstrated in the left column in Fig.3. The amplitudes of the IMFs gradually diminish and IMF_5 becomes very small. Therefore,the first 5 empirical mode components are dominated for the recording at a specific frequency throughout the time history. After EMD analysis, Hilbert transform is used and the frequency components are obtained for the selected IMFs, as shown in the right column in Fig.3. Herein, as the number of IMF increases, the frequency decreases and IMF_5 contains low frequency component. For EQ1, the frequency contents below 2 Hz are dominant.

To verify the effectiveness in component decomposition, the first 5 IMFs are summated and compared with the origin recording. The left plot in Fig. 4 suggests the differences between the processed data and the origin signal. The main vibration from 15s to 30s are extracted and demonstrated. Tiny differences indicate that 5 cyclic analyses for IMFs are adequate to reconstruct the origin signal. Therefore, all the frequencies in different IMF are added together and the frequency component of the processed data is determined. Comparing the frequencies of origin data and the processed data is demonstrated in the right plot in Fig. 4. The frequency contents are greatly similar in frequency higher than 1Hz. However, the lower frequencies are not consistent well. That means the component with lower frequency is eliminated in data process and that frequency for the processed data is enhanced within the lower frequency extent.

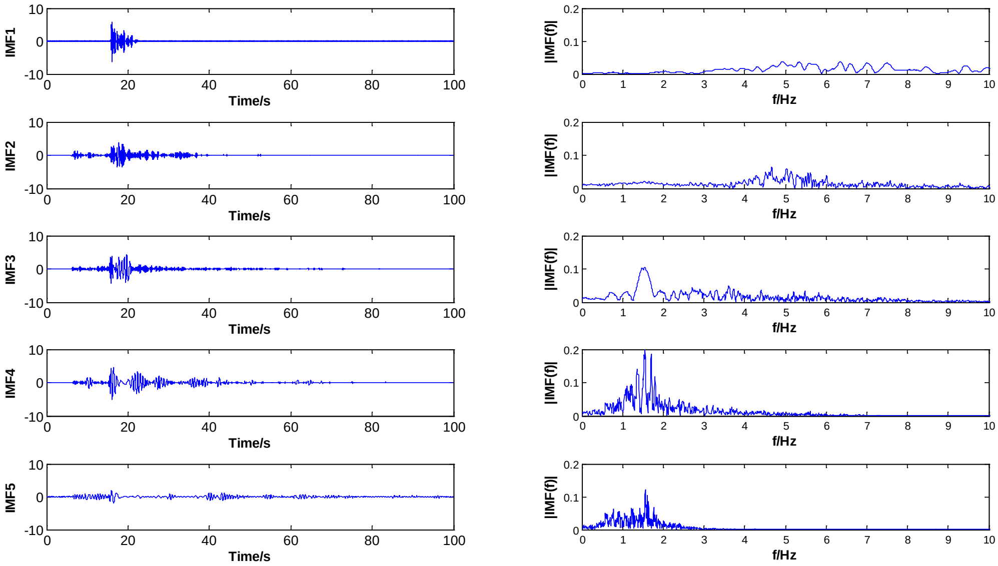

Fig. 3 The first 5 IMFs and its frequency content

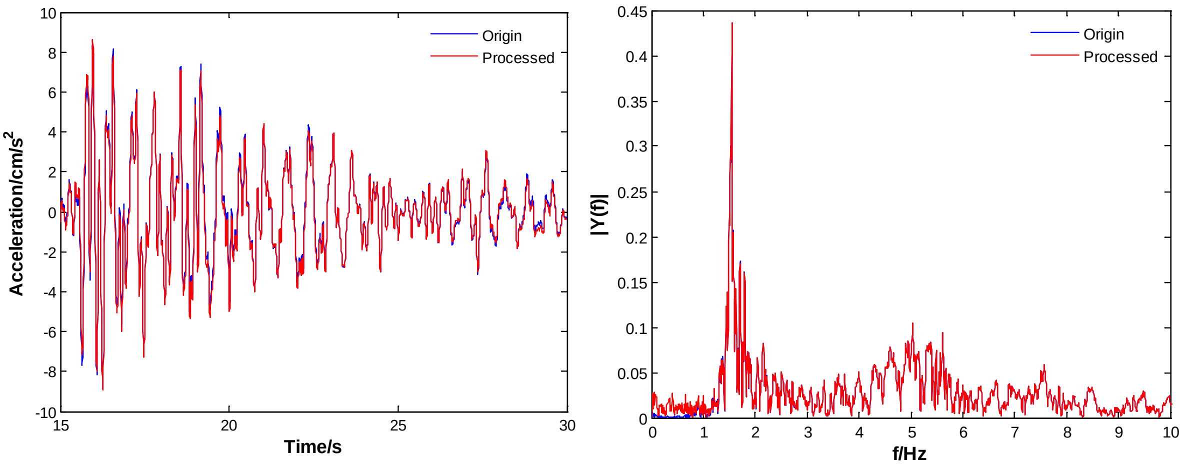

Fig. 4 Acceleration waveform and frequency comparsion between origin data and processed data

As indicated in Fig.4, the predominant frequency for EQ1 is well extracted using HHT method. Similarly, the frequency for EQ2 can be obtained as well. The predominant frequencies are comparable for EQ1 and EQ2 as shown in Fig.5. For better comparing, normalization is applied and the frequencies are identified. The first predominant frequency for EQ1 is 1.55Hz and 1.56Hz for EQ2. As aforementioned, the amplitudes of the input motions are of a great disparity. However, the dynamic characteristics obtained are similarly coincident. It is inferred that the characteristics are the inherent parameters and they are not changed with the vibration. This is the fundamental basis for consistency analysis. Results reveal that the consistency is satisfactory.

4. Conclusions

The dynamic response recordings are analyzed by means of HHT for two different earthquakes. The consistency is carried out and predominant frequencies are compared. The analysis indicates the

HHT method is an effective way to identify the dynamic characteristics. It simplifies the process of obtaining structural characteristics and can be used to implement the different earthquake response analysis. Analysis similarly reveals that the normalized predominant frequencies identified are seldom influenced by the input ground motion. They are inherent parameters and it is inevitable. The favorable consistency highlights the effectiveness of HHT application. The frequency contents are also comparable in target frequency band. The input energies are diverse for two earthquakes and differences in amplitude are noteworthy merely.

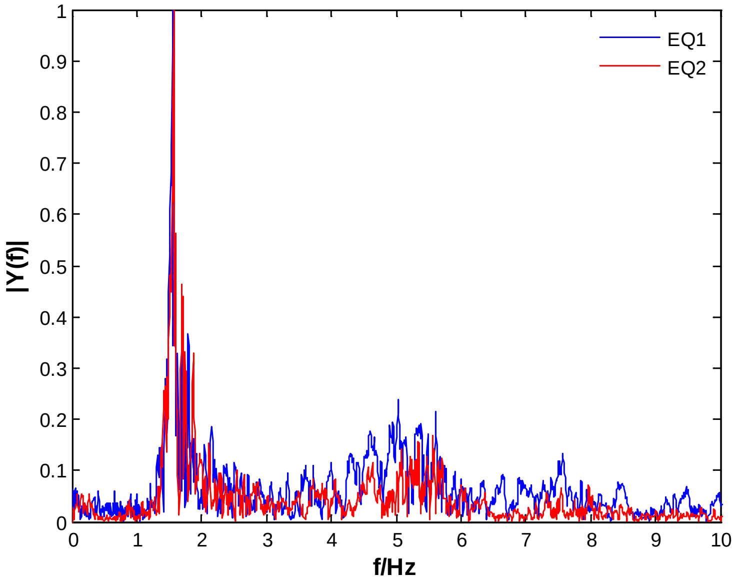

Fig. 5 Normalized frequency for EQ1 and EQ2

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