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A Case Study on Modal dynamic Identification of building from Mild earthquake responses

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Abstract

In last two decades, operational modal analysis is widely used for modal identification of structures which uses ambient responses of structure for determining the modal parameters and Frequency Domain Decomposition is one of the most popular method, but seismic excitations and high damping values of structures do not satisfy the assumptions of this classical method. The dynamic modal parameters derived from earthquake responses are more reliable than those from small amplitude responses since dynamic properties of civil structures are dependent on amplitude. In recent years, a new algorithm known as refined Frequency Domain Decomposition (rFDD) is developed which uses structural response to strong ground motions that can be short in duration and is applicable for structures with light to heavy damping. The refined Frequency Domain Decomposition (rFDD) algorithm was initially developed using synthetic seismic response signals as input and later real strong motion response records were used to demonstrate the effectiveness of this algorithm for modal dynamic identification of structures under real earthquake excitations. This method is well developed to counter the problems that normally arise in modal identification and in cases of heavy damping and non-stationarity of the signal, making it lengthy and tedious to process. In this paper the main feature of this method which is Integrated Power Spectral Density matrix computation is taken and applied on mild earthquakes responses of structure. The modal parameters identified are then compared with target values obtained from classical FDD method using ambient responses and interpreted, presenting a case for usage of rFDD in simplified manner in modal dynamic identification of structures.

Keywords: Operational Modal analysis, mild earthquake response, refined Frequency Domain Decomposition

1. Introduction

Among Operational modal analysis methods, frequency domain methods are easy to use than ones developed for time domain and Frequency Domain Decomposition method [1] is the most popular one among them due to its user friendliness. For long term structural health monitoring purposes this method is very suitable, but it has its drawbacks. The assumptions of light damping and stationary input limit its usage in cases of highly damped structures and earthquake responses. Although occurrence of strong earthquakes is less probable, mild to moderate earthquakes are more frequent in comparison.

In recent years, a new algorithm rFDD [2] is proposed which addresses the above-mentioned critical issues in modal identification of structures. This method is thoroughly investigated using synthetic earthquake responses of structural models [3] and the case of real strong motion structural response is also well discussed [4]. But the number of steps involved in this algorithm makes it less user friendly when compared to FDD. In past, the classic FDD algorithm is used to in case of weak earthquake due to building demolition and modal parameters identified are less than approximate [5].

In this paper, an attempt is made to explore the possibility of a simplified approach for modal identification of structures using mild earthquake responses. For the same, structural responses to moderate earthquakes recorded using micro-tremor vibration sensors which are installed on RC building with unreinforced brick masonry infills, located in Chandigarh, India which lies in moderate-to-severe earthquake zone, are used.Although a single strong earthquake can test the structural health of a structure and may cause significant damage in some cases, frequent mild earthquakes deteriorate the strength and stiffness of the structure gradually over a period of time and cannot be ignored henceforth.

The main step of rFDD algorithm, which is computation of integrated PSD matrix, implements simultaneously both Wiener - Khinchin [6] and Welch's modified periodogram [7] methods. A good advantage is taken from both the methods where the Wiener- Khinchin 's approach works well especially with short signals and allows for a clearer detection of the peaks for all Singular Value curves. And the Welch's method implements averaging and windowing before frequency-domain convolution and leads to slightly better mode shapes despite the not so-good separation of the signals in the modal space [4]. This step from rFDD is merged with classical FDD algorithm and the modal parameter results obtained from this approach are compared with target values obtained from ambient vibrations the structure.

2. Integrated approach for PSD matrix computation

In classical FDD method, the PSD matrix output $G_{yy}(\omega)$ Power Spectral Density (PSD) matrix is formed using auto and cross power spectral density functions of the input signals. In rFDD algorithm first the frequency interval is selected in which modal parameters are to be identified. The output PSD matrix $G_{yy}(\omega_{sub})$ selected for the frequency intervalω_{sub}, shall be computed through numerical methods. The integrated approach for PSD matrix computation presented in this work simultaneously implements the Wiener – Khinchin and the Welch’s modified periodogram methods in a consecutive way.

The Wiener–Khinchin algorithm is based on the direct Fourier Transform (FT) of the de-trended correlation matrix R_{yy}^{detr} (τ) [3], in order to obtain the PSD matrix of the responses G_{yy}^{detr} (ω_{sub}):

$$G_{yy}^{detr}(\omega_{sub}) = \mathcal{F}\left[R_{yy}^{detr}(\tau)\right] \qquad \text{eq.1}$$

$$G_{yy}^{detr}(\omega_{sub}) = \mathcal{F}\left[\overline{\emptyset} R_{pp}^{detr}(\tau)\emptyset^{T}\right] \qquad \text{eq.2}$$

$$G_{yy}^{detr}(\omega_{sub}) = \overline{\emptyset} G_{pp}^{detr}(\omega_{sub})\emptyset^{T} \qquad \text{eq.3}$$

Where $G_{pp}^{detr}(\omega_{sub}) = \mathcal{F}[R_{pp}^{detr}(\tau)]$ is the response PSD matrix (in terms principal coordinates p_i), obtained as FT of the un trended correlation matrix $R_{pp}^{detr}(\tau)$ [3], expressed again in principal coordinates. Then, Singular value decomposition is done for this matrix. This method is called *Correlation Approach (Corr)*.

After the use of the Corr approach, the second method adopted is the estimation of the $G_{yy}(\omega_{sub})$ matrix uses Welch's modified periodogram:

$$G_{yy}^{detr}(\omega_{sub}) \cong \frac{1-r}{k}\sum_{k=1}^{k/1-r} \frac{\left[\sum_{t=0}^{L-1}\bar{y}_k(t)w(t)e^{-i\omega\frac{t}{L}}\right]\left[\sum_{t=0}^{L-1} y_k^{T}(t)w(t)e^{-i\omega\frac{t}{L}}\right]}{\sum_{t=0}^{L-1} w(t)^2} \qquad \text{eq.4}$$

where *K* is the number of segments of length *L* and overlapping *r* (*r* = 2/3 in the present work) in which the initial signal **y** (*t*) has been divided, $\mathbf{y}_k(t)$ is the *k*th segment of the original signal and W(*t*) is the considered windowing function, i.e. an Hanning window as in this case. The method resumed in eq.4 is called *Welch Approach (Welch)*.

The rFDD algorithm efficiently uses of simultaneous implementation of both Corr and Welch methods, into an integrated process. First, a run with the Corr approach is performed, by applying the peak-picking procedure on the sharper and better defined singular values obtained. The peak-picking technique is assisted by the use of MAC, Auto-MAC, MPC, and Auto-MPC indexes [8] [9], by comparing the mode shapes of each potential peak with those of the others in its proximity. In this way, the correct peaks (i.e., the correct frequency lines related to the modes of vibration) may be detected. This method works well especially with short signals, though it may produce slightly less accurate mode shapes. Peaks may also be detected on lower Singular Value curve.

The correlation approach might produce slightly less accurate mode shapes; therefore, Welch's method is applied sequentially to extract the final parameter estimates. This is done by adopting the resonance frequency lines $\omega = \omega_k$ arising from the Corr method. Then, the PSD matrix is recomputed by Welch's approach, extracting the modal estimates in correspondence to the detected frequency lines of resonance peaks from corr method. In this manner, the correlation approach contributes in detecting the correct resonance peaks, allowing to process the noisy singular values more effectively that may arise from Welch's procedure, which otherwise would return merged and doubtful peaks.

3. Details of building and mild earthquake responses selected for the study

A four storey government school building in Chandigarh, India was selected for monitoring its floor vibrations and was instrumented with vibration sensors on all floors. Chandigarh city was selected for this study since it's located near the Himalayan mountain range and it's a seismically active zone. Frequent mild to moderate earthquakes are experienced in this area and the epicenters of these earthquakes are from near to as far as Iran-Pakistan and Afghanistan border. This city lies in Zone IV as per Indian Code [10].

Fig.2 shows plan view of the building which has two blocks separated by expansion joint.

Fig.1– Government School building, chandigarh, India.

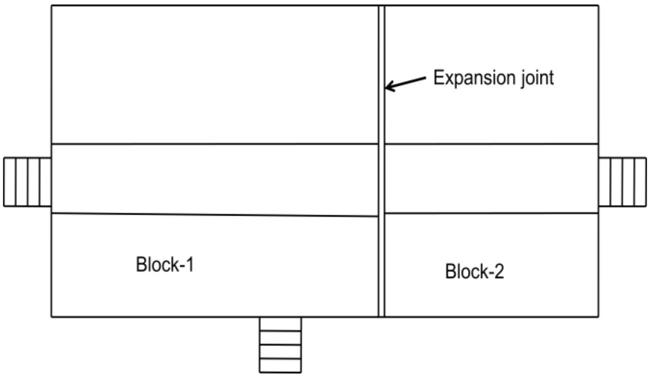
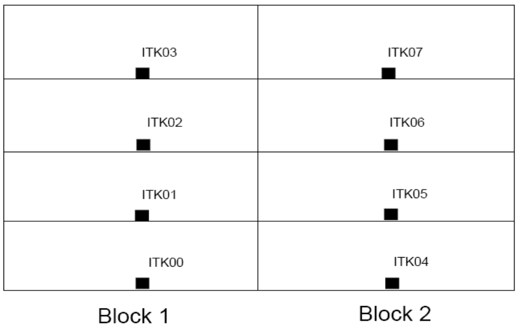


Fig.2– Plan View

The two blocks of this building are installed with sensors on all the floors. Fig.3& 4 shows the sensor locations in the building in plan and elevation. The N-S and E-W components of the sensors are oriented with respect to the length and width of the building. The responses of Block1 to mild earthquakes is considered for the study.



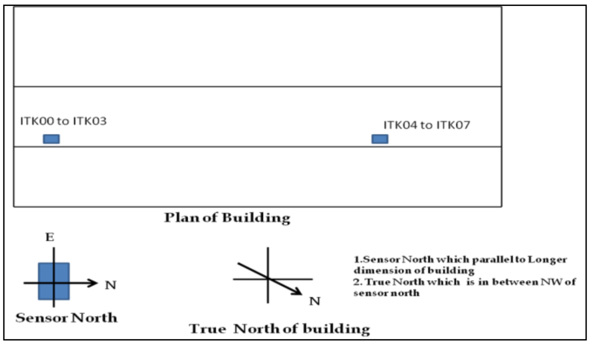


Fig.3– Sensor Location in elevation.

Fig.4– Sensor Location in Plan.

Two mild earthquakes are considered for this study (Table 1). The target modal properties for this study are obtained from modal identification of ambient vibrations recorded two weeks before the first earthquake, using classical FDD algorithm. Fig.5 shows the N-S and E-W components of earthquake recorded at the sensors installed on the ground floor of the building.

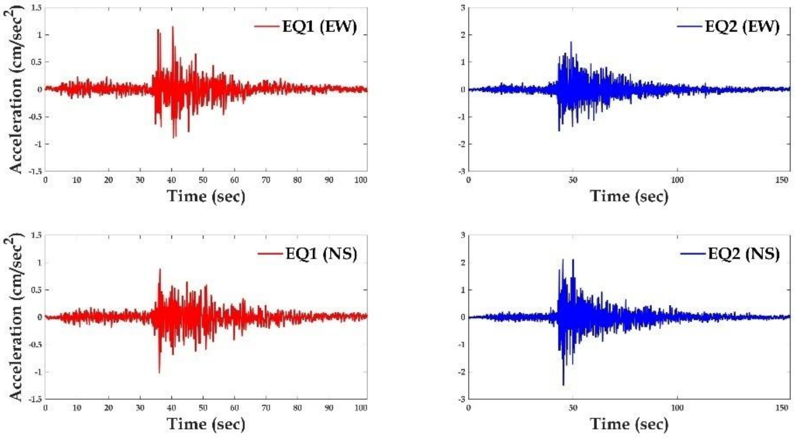


Fig.5- ground motion time history of earthquakes recorded ground floor of selected building

Table 2: Details of Selected earthquakes

	Earthquake Location	Date	Magnitude	Distance from Epicenter (Km)	Duration (sec)
EQ1	J&K, H.P Border, India	9th July 2013	5.1	285	140
EQ2	Jammu & Kashmir, India	2nd August 2013	5.4	331	102

4. Analyses and Discussion on results

The mild earthquake responses of the structure recorded on all floors are taken as input for proposed approach. The response data is first de trended and then filtered between 0 to 10 Hz using low pass Butterworth filter in MATLAB. The frequency range is selected with respect to the frequency range of structures.

The filtered input data is used for computation of integrated PSD matrix. First Wiener–Khinchin algorithm is used to generate PSD matrix. In this process auto and cross correlation function matrix of building responses is generated. Then discrete Fourier Transform of correlation functions is done to obtain the PSD matrix. Singular Value Decomposition of this PSD matrix gives the singular values as shown in Fig.6-9.

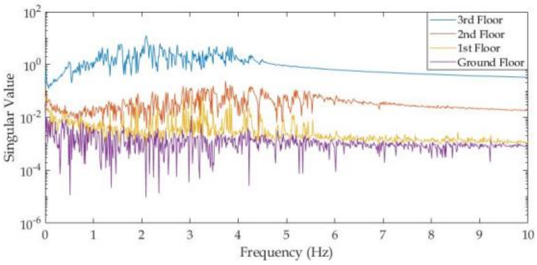


Fig.6– SVD obtained by a Corr method for NS component of Earthquake EQ1

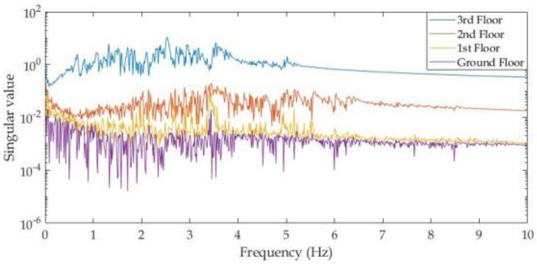


Fig.7– SVD obtained by a Corr method for EW component of Earthquake EQ1

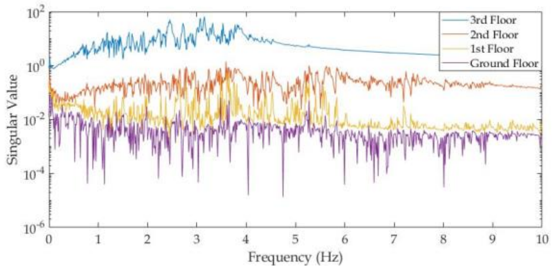


Fig.8– SVD obtained by a Corr method for NS component of Earthquake EQ2

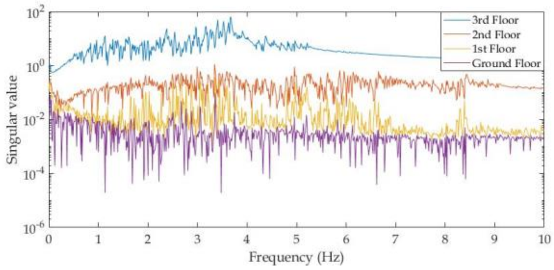


Fig.9– SVD obtained by a Corr method for EW component of Earthquake EQ2

Using peak picking method, sharper and better singular value peaks are selected, and the mode shapes of each peak is compared with singular vectors of those in proximity using MAC index [8]. In this process only the modal peak could not be identified properly. As seen in fig.6-9, the amplitudes of singular values are all low and near range making it difficult to identify the modal peaks. The MAC index was calculated on several peaks and it is observed that frequency range of assumed SDOF of a peak overlap with assumed SDOF of other peaks even for MAC values of 0.9. This made the identification of first mode very impossible. And due lower amplitudes in all singular value curves, peaks for higher modes could not be peaked with confidence. The expected modal estimates could not be obtained. Therefore, the objective of this study could not be achieved. Hence, the expected modal estimates could not be obtained, and the objective of this study was not achieved.

5. Conclusion

As discussed earlier the objective of this study is to explore the possibility of simplified approach for modal identification of structures using mild earthquake responses. The rFDD algorithm from which this study has been partially inspired delivers good results for strong ground motions responses. In the current study, where integrated PSD matrix computation procedure is used with classical FDD method the expected results could not be achieved due to low amplitudes in modal estimates. This is due low magnitudes in building responses. This can be the same even if complete rFDD algorithm is used. It has to be explored upto what lower magnitudes of earthquakes and amplitudes of ground motions this algorithm delivers efficient results. Applying this algorithm or the proposed approach on wide range of earthquake responses could provide valuable information in simplification of modal identification procedure in cases of non stationary input. This can be a scope of future work provided the necessary data for wide range of earthquakes is available.

6. References

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