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PREDICTION OF DYNAMIC PARAMETERS OF STRUCTURES BASED ON MODAL ANALYSIS USING FDD

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Abstract: Dynamic behavior and system identification are important topic in monitoring and maintaining existing infrastructures. System identification using Frequency Domain Decomposition (FDD) is an operational modal analysis (OMA) in frequency domain used on experiment of shear frame model with random vibration method is validated by comparing output of FDD data using acceleration input from simulated model with output of FDD using acceleration result of experimental model. The result of acceleration data is recorded using USB accelerometer X16-1D then calibrated and analyzed using Matlab programs, data_procces.m and solve FDD_eksperiment.m to estimate the modal parameter of model structure. Compared with parameter modal of simulation model, FDD method with input simulated acceleration resulted in difference of 1.757% in first frequency and 0.462% in second frequency. Meanwhile for FDD method using acceleration of experimental model, resulted in difference of 6.3126% in first frequency and 7.7327% in second frequency. FFD method is fairly accurate in predicting the frequency of structure, but for difference of mode shapes in experimental is very big compared to simulated model therefore it can be concluded that, this modal parameter is cannot be detected in experimental model.

Keywords: Frequency Domain Decomposition, operational modal analysis, modal parameter of structure, shear frame

Abstrak: Perilaku dinamik dan identifikasi sistem adalah topik yang penting pada pengawasan dan pemeliharaan infrastruktur yang sudah ada. Identifikasi sistem menggunakan Frequency Domain Decomposition (FDD) yamg merupakan analisis modal operasional (OMA) pada domain frekuensi digunakan untuk eksperimen pada model rangka geser dengan getaran acak. Metode FDD divalidasi dengan dengan membandingkan output dari FDD menggunakan input percepatan dari hasil simulasi dengan output FDD menggunakan input percepatan dari model eksperimental. Hasil dari data percepatan direkam menggunakan USB accelerometer X16-1D yang kemudian dikalibarasi dan dianalisis menggunakan perintah load program Matlab data_procces.m dan solveFDD_eksperiment.m untuk mengestimasi parameter modal dari model stuktur. Dibandingkan dengan parameter modal dari model simulasi, metode FDD dengan in-put simulasi percepatan menghasilkan perbedaan sekitar 1.757% pada frekuensi pertama dan 0.462% pada frekuensi kedua. Sedangkan metode FDD dengan input percepatan dari model eksperimental, menghasilkan perbedaan sekitar 6.3126% pada frekuensi pertama dan 7.7327% pada frekuensi kedua. Metode FDD menghasilkan hasil yang cukup akurat dalam memprediksi frekuensi dari stuktur, tetapi hasil perbedaan dari ragam bentuk pada model eksperimental sangat besar dibandingkan model simulasi, sehingga dapat disimpulkan bahwa parameter modal ini tidak dapat dideteksi pada model eksperimental.

Kata kunci: Frequency Domain Decomposition, analisis modal operasional, parameter modal struktur, portal geser

BACKGROUND

OMA can be defined as the modal testing procedure that allows the estimation of the modal parameters of the structure only from measurements of the vibration response. The idea behind OMA is to take advantage of the excitation due to ambient forces and operational loads (wind, traffic, micro-tremors, etc.) to replace the artificial excitation method. Compared to artificial excitation method, OMA method is more economical and practical. There are two main method in OMA, one is the identification in the time domain and the others is in frequency domain. One of the most accurate methods in frequency in frequency domain are Frequency Domain Decomposition. This technique was introduced by Brincker et al. (2000) as improvement of basic "peak-picking" method to better sepa-ration of closely spaced modes and offer method to more accurately estimate the damping ratio.

This research using Matlab code implementation of FDD method developed by Cheynet et al. (2016) to extract dynamics parameter of model structure and comparing it to the numerical simulation of the model. If the result of experiment is consistent with pre-diction, then it can be concluded that FDD method is adequate to measure the dynamic parameter of shear frame.

POWER SPECTRAL DENSITY

Power spectral density is the function of time series that describe distribution of power into frequency component of that signal. The auto spectral density function for a time series $x(t)$ is defined as the Fourier transform of the correlation function $R_x(\tau)$.

$$G_x(\omega) = \frac{1}{2\pi}\int_{-\infty}^{\infty} R_x(\tau)e^{-i\omega\tau}d\tau \quad (1)$$

conversely the correlation function can be found from the inverse relation is

$$R_x(\tau) = \int_{-\infty}^{\infty} G_x(\omega)e^{i\omega\tau}d\omega \quad (2)$$

FREQUENCY DOMAIN DECOMPOSITION METHOD

In the Frequency Domain Decomposition (FDD) identification, the first step is to estimate the power spectral density matrix. The estimation of the output PSD known at dis-crete frequencies is then decomposed by taking the Singular Value Decomposition (SVD) of the matrix

$$\hat{G}_{yy}(j\omega_i) = U_i S_i U_i^H \quad (3)$$

SIMULATION TARGET MODEL

Model of 2-story frame structure is made in Matlab using Matlab program developed by Arfiadi (1996) for structure analysis of 2D frame. The structure dimension are 0.3m x 0.3 m with 0.4 m height for each floor. The mass of each floor are 7 kg or 0,007 ton. Modulus elasticity of steel used for this model is 200.000 MPa. With damping ratio of the structure set to 5 % or 0,05. The structure detail can be seen in figure1 below.

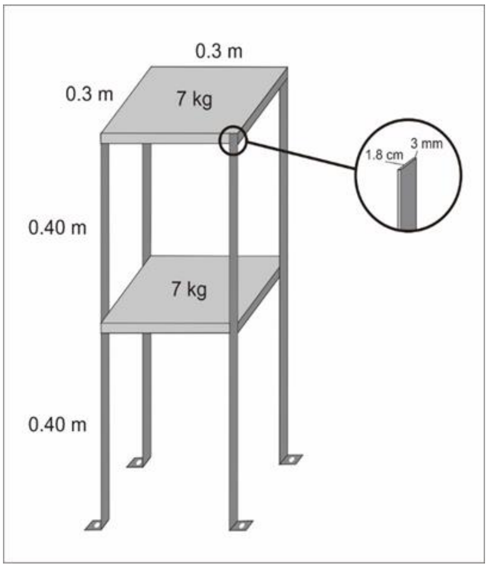

Figure1. Mode shapes 1 and 2

These parameters are inputted into Matlab model then the program will analyze the structure using Stiffness Matrix Method with static condensation to reduce the degree of freedom the structure is evaluated, leaving only the lateral stiffness. The result of the program will be the structure frequency, pe-riod and mode shape as shown below.

f1 = 2.0261 Hz T1 = 0.4926 s
f2 = 5.3414 Hz T2 = 0.1872 s

With mode shapes for first and second modes shown in Table 1 and Figure 1.

Table 1. Mode shapes

Modes	Floor	
	1	2
Mode 1	0.6124	1.0000
Mode 2	-1.6331	1.0000

These parameters are then used as target parameter for both FDD analysis in simulation and experimental model. The difference between these target number and the FDD analysis's number will be used to measure the accuracy of the method.

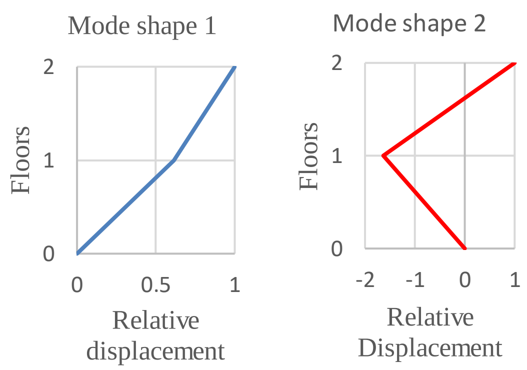

Figure 2. Mode shapes 1 and 2

SIMULATION FDD MODEL

For the simulation of ground motion the random command, randn ( ) in Matlab will be used to generate random motion with maximum range of acceleration 0.15g with total data 500,000 point. Then using ss ( ) function the model data is transformed into state-space system. The system together with motion data are inputted to function lsim ( ) to simulate the structure response. Then the acceleration can be calculated from the response output. The structure acceleration response for both floors can be seen in Figure 2 above.

The response the data of floor acceleration generated from the program is then fed into FDD analysis program to calculate frequency, mode shape and damping ratio of the structure Using FDD method with parameter total mode, Nmodes = 2 and sampling frequency, fs = 100 Hz. Then from the Singular Value Diagram select and pick two frequency that are the highest value of two peaks on the diagram.

From these two frequencies, the mode shape and damping ratio are calculated using logarithmic decrement method. The result and comparison of frequency, mode shapes, and damping ratio can be seen in Table 2, 3, and 4.

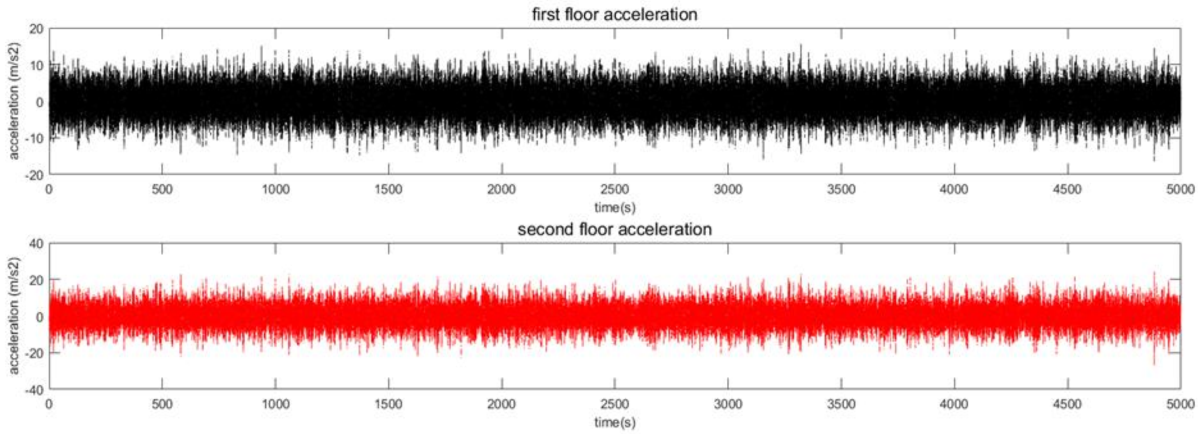

Figure 3. Simulation of structure response

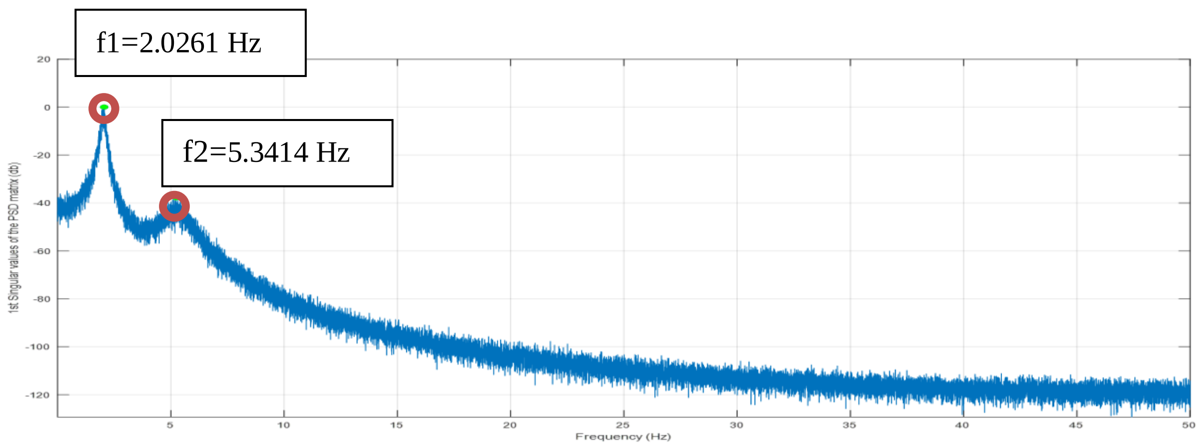

Figure 4. Singular value of PSD matrix

From data above, it can be seen that FDD method is very accurate about 0.46–1.74% (less than 5 percent difference) to predict the frequency. And very accurate for mode shapes, looking at the mode shape of the structure resulted in 2.06–5.17%. For predicting damping ratio this method resulted at 3% and 16% difference.

EXPERIMENTAL FDD MODEL

For the experimental model, the dimension will be similar with the simulation model. The model is made with steel with modulus elasticity of 200,000 MPa, with concrete block plus wooden plank for the floor. Each floor has total weight about 7 kg and the structure is bolted into simple shaking table.

For recording the acceleration data two MEMS acceleration sensor used on each stories of the frame model. The sensor rate is set to 100 Hz or 100 data per second, with maximum data set to 500,000 for duration of 5000 second or 1 hour 23.33 minutes.

To calibrate the data into acceleration data (m/s2), the file is edited using Matlab program data_process.m. First the data is divided by 2080 to calibrate the data into g (gravity acceleration) and then multiplied by 9.81 m/s2. There are three channel for the acceleration data; x,y, and z, for this research only vibration in x axis will be considered as the shaking table is only one directional. The result of the acceleration data of two floors calibrated is shown in Figure 4.

The response the data of floor acceleration generated from the program is then inputted into FDD analysis program to calculate fre-quency, mode shapes and damping ratio of the structure Using FDD method with parameter total mode, Nmodes = 2 and sampling frequency, fs = 100 Hz. Then from the Sin-gular Value Diagram select and pick two peak frequency of the diagram.

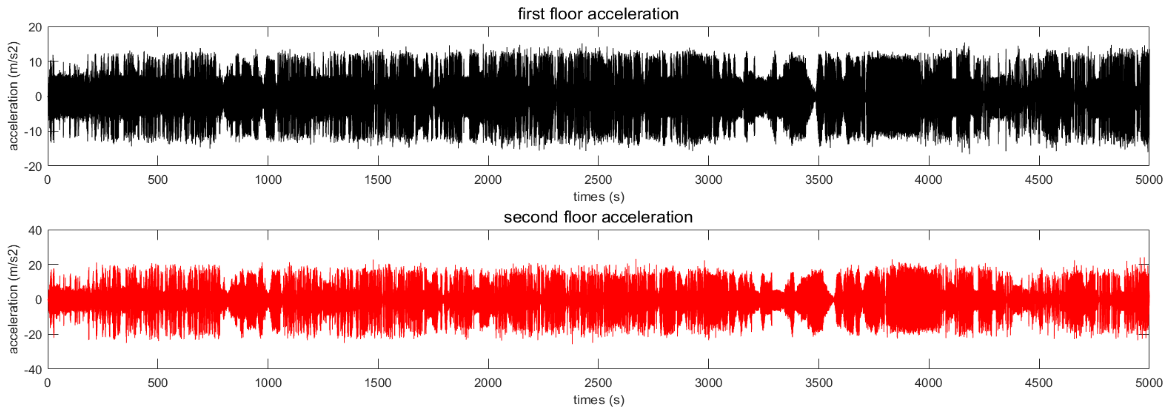

Figure5. Experimental structure response

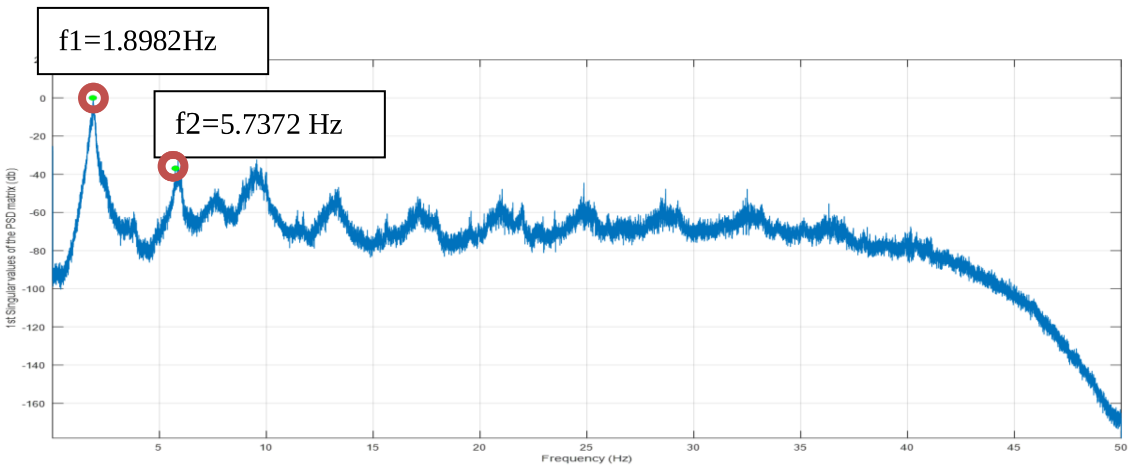

Figure6. Singular value of PSD matrix

From these two frequencies the mode shape is calculated using logarithmic decrement method. The result and comparison of frequency and damping ratio can be seen in table 5 and 6.

Table 5. Frequency Comparison between FDD Simulation Method and FDD Experimental Method

Mode frequencies	Target eigenfrequencies	Measured eigenfrequencies	Differences	Percentage
Frequency Mode 1	2.0261 Hz	1.8982 Hz	0.1279	6.3126%
Frequency Mode 2	5.3254 Hz	5.7372 Hz	0.4118	7.7327%

Table 6. Comparison of Modeshapes between FDD Simulation Method and FDD Experimental Method

	Target Modeshapes		Measured Modeshapes		Differences		Percentage	
Modes	1st	2nd	1st	2nd	1st	2nd	1st	2nd
1st floor	0.612	-1.633	-0.622	0.927	1.234	2.56	201.63%	156.77%
2nd floor	1	1	1	1	0	0	0	0

From data above, it can be concluded than FFD method on experimental model is fairly accurate about 6.31 – 7.73 % (less than 10 percent difference) to predict the frequency of the structure. Nevertheless, for the mode shapes of structure the deviation of measured result is significant, 201.63% and 156.77 %. Therefore, can be concluded that FFD method cannot detect mode shapes property in the data and cannot be used.

CONCLUSION AND SUGGESTIONS

Based on discussion on analysis result on simulation analysis and experiment analysis, can be take several conclusions:

1. From simulation analysis of FDD, it can be concluded than FDD method is very accurate (less than 5 percent difference) to predict the frequency and mode shape of structure in idealized environment without noise in the signal and fairly good for predicting damping at maximum 16% difference.
2. From experimental analysis, it can be concluded than FFD method on experimental model is fairly accurate (less than 10 percent difference) to predict the frequency of the structure. But for mode shape of structure the difference from target is significant, therefore can be concluded that FDD method cannot detect these properties in the data.

Based on discussion on analysis result on simulation analysis and experiment analysis, several point can be improved in this research:

1. The damping of structure has not been calculated therefore cannot be compared with FDD data, more structure's data such as damping should be calculated to be compared with the result of FDD method.
2. FFD method is accurate in idealized environment with clean signal compared to experimental data which have many peaks generated from noise in the signal. Therefore, with better quality data and method to isolate desired mode shapes, the result can significantly improve.
3. Processing method to improve the quality of data is needed such as detrend, denoising algorithm, and filtering algorithm for the data.
4. The source of the random vibration can be changed to simulate more realistic load on building such as loading vibration or wind vibration.

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