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Automation of Frequency Domain Decomposition for Operational Modal Analysis using Finite Element Model

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Abstract

Modal parameters are applied for prediction and analysis of structural behaviour and finite element model updating which is essential for a structural health monitoring system. This research proposes a revised procedure of modal parameter selection in frequency domain decomposition for operational modal analysis. The suggested method extracts modal parameters successfully and automatically.

Keywords: Operational modal analysis, Frequency domain decomposition, Model updating, Finite element method, Structural health monitoring

1 Introduction

Structural health monitoring (SHM) systems are necessary for efficient maintenance and management of residual life of a structure. The SHM system frequently utilizes a finite element model which describes real structural behaviour accurately. The high precision model can be obtained through model updating using modal parameters.

Modal parameters can be obtained from “Operational Modal Analysis” (OMA), called an output only modal testing, in which output response of the structure during operational state is utilized [1-4]. OMA has been widely used for large structures such as offshore structures where it is difficult to apply artificial random excitation. One of the representative methods for OMA is “Frequency Domain Decomposition” (FDD) method. During this FDD process, proper modal parameters should be selected from many possible modal parameters. Depending on the selection, FDD results can be

varied. The aim of this study is providing a new procedure to automatically select modal parameters for more accurate FDD.

2 Methods

Structural response like acceleration can be approximated by a linear combination of the finite number of modal shapes

$$\mathbf{y}(t) = \mathbf{\Phi}\mathbf{q}(t) , \quad (1)$$

where $\mathbf{\Phi}$ is the modal shape matrix and \mathbf{q} is the modal coordinate vector. The covariance matrix of response \mathbf{y} is expressed using Eq. (1), and the power spectral density matrix is calculated by transforming the covariance matrix to frequency domain as follows:

$$\mathbf{C}_{yy}(t) = \mathbf{\Phi}\mathbf{C}_{qq}(t)\mathbf{\Phi}^T , \quad (2)$$

$$\mathbf{P}_{yy}(f) = \mathbf{\Phi}\mathbf{P}_{qq}(f)\mathbf{\Phi}^T , \quad (3)$$

where \mathbf{C}_{yy} is the covariance matrix and \mathbf{P}_{yy} is the power spectral density matrix. Singular value decomposition of the power spectral density matrix is expressed as

$$\mathbf{P}_{yy}(f) = \mathbf{U}(f)\mathbf{S}(f)\mathbf{U}(f)^T , \quad (4)$$

in which the left singular vector matrix \mathbf{U} and singular value matrix \mathbf{S} correspond to $\mathbf{\Phi}$ and \mathbf{C}_{qq} , respectively. Fig. 1 shows an example of singular values at each frequency obtained from Eq. (4).

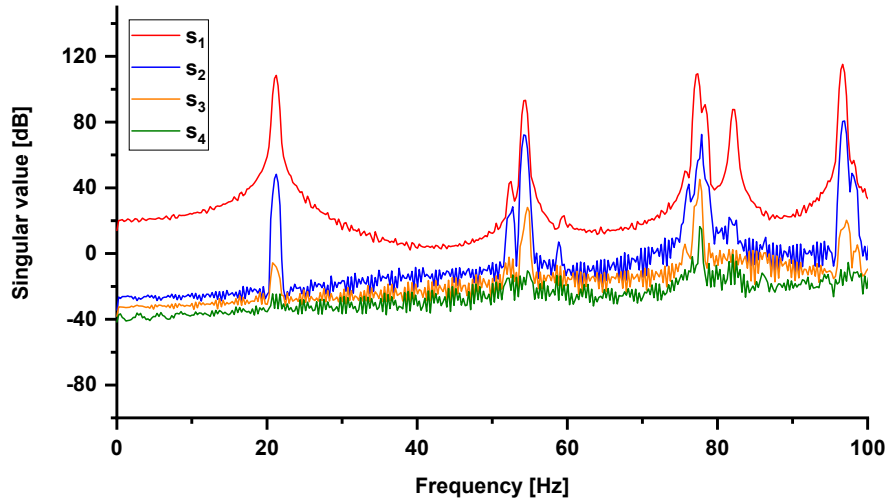


Figure 1: Singular value curves.

Proper modal points are selected in these curves, and then natural frequencies correspond to the frequencies of the selected points and modal shapes correspond to the singular vectors compared to the selected singular values. In order to select modal points automatically, this study utilizes modal parameter results as references

obtained from an ideal finite element model, in which material properties without any damage and well-posed boundary conditions are considered. A frequency and singular vector at a possible modal point of FDD are compared with those of reference modal parameters, and the point showing a minimum difference is selected as modal points corresponding to the reference modal parameters. The section procedure is summarized as below:

(Step 1) Possible candidates for modal points are collected from singular value curves. Basically, peak points and points around the peaks are included.

(Step 2) A reference modal shape is compared with that of candidates to calculate the difference between them. The difference is defined in Eq. (5)

$$d_{ij} = 1 - MAC(\mathbf{f}_{ref}^{(i)}, \mathbf{f}_{candi}^{(j)}) \quad \text{with} \quad MAC(\mathbf{v}_1, \mathbf{v}_2) = \frac{\mathbf{v}_1 \cdot \mathbf{v}_2}{\|\mathbf{v}_1\| \|\mathbf{v}_2\|} \quad (5)$$

(Step 3) The point having the minimum difference is selected as the modal point corresponding to the reference modal parameters.

(Step 4) Step 2 is repeated until all of the reference parameters are compared.

3 Results

The suggested procedure is applied to a numerical experiment with an offshore jacket structure. An ideal model for reference modal parameters is shown in Fig. 2(a), in which Young's modulus is E_0 and density is ρ_0 . Fig. 2(b) shows a model with loading points for the numerical experiment, which have a variation of Young's modulus and density partially.

Candidate points marked with hollow symbols on the singular value curves in Fig. 2(c) are compared with the reference modal parameters. The points having the minimum difference d_{ij} are selected as modal points and marked with solid symbols. Table 1 shows the MAC values between FDD results and corresponding natural frequencies. The first five points selected show high accuracy and the other points show large differences.

Mode #	MAC [-]	f_{FDD} [Hz]	f_{sol} [Hz]
1	0.9324	21.24	21.18
2	0.9328	21.24	21.18
3	0.9972	52.49	52.90
4	0.9895	54.20	54.83
5	0.8947	52.73	54.88
6	0.5304	63.72	55.53
7	0.8753	58.84	59.68
8	0.2057	81.54	77.43

Table 1: Comparison of modal parameters from FDD with those of the numerical experimental model

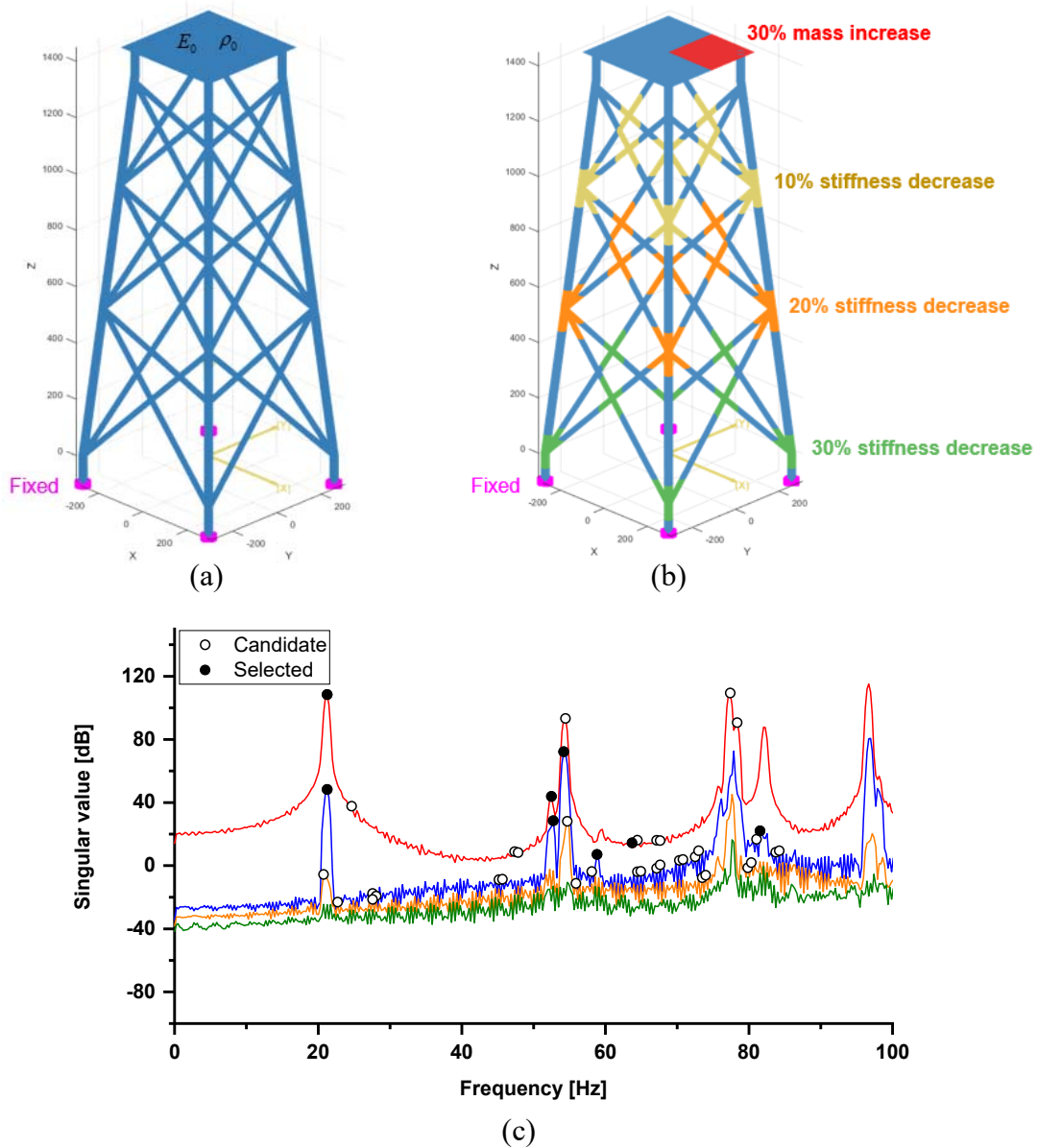


Figure 2: Example of the offshore jacket structure: (a) Ideal finite element model; (b) Numerical experimental model; (c) Modal points selected and candidate points on singular value curves

4 Conclusions and Contributions

This study proposed a new modal selection procedure in the frequency domain decomposition method for the operational modal analysis. The method is applied to an offshore structure numerically and the result shows that the suggested method can find modal points with high accuracy. Using the modal analysis results obtained from the ideal finite element model as reference modal parameters, modal points can be selected automatically and more easily compared to other methods. In addition, this

procedure could find modal points on the same frequency, which usually occurs in structures with symmetric geometry.

Acknowledgements

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