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Comparison of Deterministic and Stochastic Method in Operational Modal Analysis in Application for Civil Engineering Structures

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Abstract

Applying Operational Modal Analysis (OMA) one can extract modal properties of structure (eigenfrequencies, eigenforms and modal damping) on the basis of vibration measurement only - without excitation measurement, what is very complicated in case of big structures. This great advantage of OMA makes this method more common for civil engineering application. The two main techniques are used in OMA, one uses data processing in time domain, the second in frequency domain. The paper presents the comparison of these two method in application OMA for engineering structures.

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Keywords: modal analysis; time domain; frequency domain; engineering structures

1. Introduction

Nowadays architectural designing, due to more and more slender structures, force the dynamic analysis of those structures. Civil engineers have to apply apart from theoretical analysis, also some kind of experimental techniques. The basic one and the most frequently used in automotive industry is Experimental (or Classical) Modal Analysis (EMA). Applying EMA one has to measure the excitation of the structure. This is almost impossible with large civil engineering and make EMA useless for this type of application. Instead of EMA, Operational Modal Analysis OMA could be employed. The biggest advantage of OMA is that there is no need of excitation measurement. Modal parameters (eigenfrequencies, eifgenforms, modal damping) could be estimated when the structure is excited by environmental (wind, water flow, etc.) or technology influences (traffic, pedestrian movement). The only one condition should be satisfied, the excitation may be treated as white noise. Using OMA applies two main types of algorithms: a time domain and frequency domain. Those two approaches are shortly presented and differences in results are discussed.

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Nomenclature

[ ]	matrix
{ }	vector
$[\ ]^{T}, \{\ \}^{T}$	matrix, vector transposition
$(\ )^{*}, [\ ]^{*}, \{\ \}^{*}$	complex conjugate of number, matrix , vector
$[\ ]^{H}, \{\ \}^{H}$	matrix, vector Hermitian transformation

2. Theoretical background

2.1. Assumptions

OMA is derived from following assumptions:

- system is linear,
- properties of system do not change in time (time-invariant system),
- system is excited by white noise,
- measurements are done in such a way that give information for analysis (eg. position of measurement points allows to observe modes).

Whereas, the first two assumptions are obvious, two last could be hard to satisfy. Assumption about white noise is still valid but as system could be excited by not “pure” white noise, the effect of OMA is identification of the structure itself, but identification of “combined-system”. Combined system consist of structure and excitation filter, forces acting on combined-system have the properties of white noise, but forces acting on the structure are filtered by excitation filter to the actual state. Filtered excitation is still stationary and broadband. In order to satisfy the last assumption, some information about the structure before measurement are needed. This leads to conclusion that, apart from basic structures, either some previous, pre-measurement analysis is needed or OMA should be applied in at least two steps.

2.2. Frequency domain method

The well-known equation of motion, written in matrix form is the starting point

$$[\mathrm{M}]\{\ddot{q}(t)\}+[\mathrm{C}]\{\dot{q}(t)\}+[\mathrm{K}]\{q(t)\}=\{\mathrm{f}(t)\}, \tag{1}$$

where: [M], [C], [K] – denote: inertia, damping and stiffness matrices, respectively, while $\{\ddot{q}(t)\}, \{\dot{q}(t)\}, \{q(t)\}$ denote acceleration, velocity and displacement vectors, respectively, also $\{\mathrm{f}(t)\}$ is a vector of external excitation. For any structure (for which the assumptions are fulfilled) the relationship between input $\{\mathrm{f}(t)\}$ and output $\{\mathrm{y}(t)\}$ is described by equation, [1], [2]:

$$[\mathrm{G}_{yy}(\mathrm{j}\omega)]=[\mathrm{H}(\mathrm{j}\omega)]^{*}[\mathrm{G}_{\mathrm{ff}}(\mathrm{j}\omega)][\mathrm{H}(\mathrm{j}\omega)]^{\mathrm{T}}, \tag{2}$$

where: $[\mathrm{G}_{\mathrm{ff}}(\mathrm{j}\omega)]$ $[\mathrm{G}_{yy}(\mathrm{j}\omega)]$ are the power spectral density matrices of input and output signal, respectively. The subscript yy denotes output to signalize that number of measuring point could be different from number of degrees of freedom, jω – frequency, [H(jω)] – frequency response function (FRF) matrix could be written in form (used also in classical modal analysis:

$$[\mathrm{H}(\mathrm{j}\omega)]=\sum_{i=1}^{n}\left(\frac{[\mathrm{R}_i]}{\mathrm{j}\omega-\lambda_i}+\frac{[\mathrm{R}_i]^{*}}{\mathrm{j}\omega-\lambda_i^{*}}\right) \tag{3}$$