ECCOMAS International Symposium **IPM 2009** on Inverse
Problems in Mechanics of Structure and Materials
April 23-25, 2009, Rzeszów–Łańcut, Poland

SUBSTRUCTURE ISOLATION FOR LOCAL STRUCTURAL HEALTH MONITORING

Jilin Hou[1,2], **Łukasz Jankowski**[2,*], **Jinping Ou**[1,3]

[1]School of Civil Engineering, Harbin Institute of Technology
Harbin 150090, P. R. of China
e-mails: hou.jilin@hotmail.com, oujinping@hit.edu.cn

[2]Smart-Tech Centre, Institute of Fundamental Technological Research (IPPT PAN)
ul. Świętokrzyska 21, 00-049 Warsaw, Poland
e-mail: lukasz.jankowski@ippt.gov.pl

[3]School of Civil and Hydraulic Engineering, Dalian University of Technology
Dalian 116024, P. R. of China
e-mail: oujinping@dlut.edu.cn

1 INTRODUCTION

This paper describes an effective method of substructure isolation for local structural health monitoring (SHM). In practice, often only a small part of a larger structure is critical and needs monitoring [1]. However, typical SHM methods require modeling or analysis of the global structure, which can be costly, time-consuming and error-prone. The proposed approach is based on the virtual distortion method [2]; the substructure is isolated from the entire structure by placing modeled fixed supports in all nodes of their mutual boundary. Therefore, given an excitation of the substructure and a measured response, the response of the substructure treated as fixed supported can be computed. Only experimental data are used for isolation, and no numerical modeling is required. A numerical experiment of damage identification in a frame-truss will be presented during the talk to validate the methodology at 5% rms measurement error level. It is omitted here due to space constraints.

2 MODELING OF FIXED SUPPORTS

The response of a structure with fixed supports added is expressed as a combination of the responses of the original structure to (1) the same load and to (2) certain virtual force distortions that act in all DOFs of the nodes with modeled supports. Linearity and small deformations are assumed. With zero initial conditions and discrete time, the responses of the modified structure in its ith DOF and of its αth sensor are thus expressed as

$$a_i(t) = a_i^{\mathrm{M}}(t) + \sum_{j,\tau\le t} B_{ij}^0(t-\tau) f_j^0(\tau), \quad \varepsilon_\alpha(t) = \varepsilon_\alpha^{\mathrm{M}}(t) + \sum_{j,\tau\le t} D_{\alpha j}^0(t-\tau) f_j^0(\tau), \quad (1)$$

or, in the matrix notation, as

$$\mathbf{a} = \mathbf{a}^{\mathrm{M}} + \mathbf{B}^0\mathbf{f}^0, \qquad \boldsymbol{\varepsilon} = \boldsymbol{\varepsilon}^{\mathrm{M}} + \mathbf{D}^0\mathbf{f}^0, \quad (2)$$

where $a_i^{\mathrm{M}}(t)$ and $\varepsilon_\alpha^{\mathrm{M}}(t)$ are the measured responses of the original structure, $B_{ij}^0(t)$ and $D_{\alpha j}^0(t)$ are the impulse-responses, while $f_j^0(t)$ is the force distortion in the jth DOF.

Since the responses in all DOFs of the fixed supported nodes vanish, that is $\mathbf{a} = \mathbf{0}$, the response of the fixed supported substructure is $\boldsymbol{\varepsilon} = \boldsymbol{\varepsilon}^{\mathrm{M}} - \mathbf{D}^0 \left[\mathbf{B}^0\right]^+ \mathbf{a}^{\mathrm{M}}$. In practice, the impulse-responses are not available, but it is possible to measure the experimental responses $B_{ij}(t)$ and $D_{ij}(t)$ to non-impulsive excitations $f_j(t)$. These measurements can be used, if the virtual force $f_j^0(t)$ is assumed to be a combination of the non-impulsive excitations,

$$f_j^0(t) = \sum_{\tau=0}^{T-1} f_j(t-\tau) c_j(\tau). \tag{3}$$

This formula, upon substitution into (1), yields two counterparts to (2), $\mathbf{a} = \mathbf{a}^{\mathrm{M}} + \mathbf{Bc}$ and $\boldsymbol{\varepsilon} = \boldsymbol{\varepsilon}^{\mathrm{M}} + \mathbf{Dc}$, which are used to compute sensor responses using purely experimental data,

$$\boldsymbol{\varepsilon} = \boldsymbol{\varepsilon}^{\mathrm{M}} - \mathbf{DB}^+\mathbf{a}^{\mathrm{M}}. \tag{4}$$

3 SUBSTRUCTURE ISOLATION

A series of modeled fixed supports can be placed in all nodes of the boundary of a substructure in order to isolate it from the rest of the global structure. The isolated substructure behaves then as fixed supported and responses by (4) to local excitations only.

In the case of arbitrarily placed fixed supports, the force distortions are applied in the DOFs of the supported nodes. However, if the aim is substructure isolation, only local response matters, and the force distortions can be applied *anywhere outside the substructure*, provided the corresponding matrix $\mathbf{B}$ is not rank-deficient. It is a practical simplification, since not all boundary DOFs of a substructure can be accessible for experimental excitation.

4 CONCLUSIONS

This paper presents an implementation-ready method for local SHM of simple, small substructures of complex global structures. Its practical implementation is simple, since

1. No numerical model of the global structure is required. Only measured response, e.g. to an impulse hammer, is necessary.
2. When used for substructure isolation, force distortions need not to be applied exactly in the boundary DOFs of the considered substructure. In fact, all DOFs of the exterior global structure can be used as long as the respective matrix $\mathbf{B}$ is not rank-deficient.

The method in the proposed form is limited to linear damages, as most of practical damages in civil engineering seem to be linear. However, a generalization to nonlinear cases is going to be investigated in further research.

REFERENCES

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