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MODEL-BASED ACTIVE VIBRATION CONTROL FOR NEXT GENERATION BRIDGES USING REDUCED FINITE ELEMENT MODELS

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Summary

Due to high vibration sensitivity of ultra-light structures, active vibration control is required in future applications. To demonstrate the efficiency, a multi-modal active vibration control system was developed and implemented for a stress ribbon footbridge at Berlin Institute of Technology. Initially, the control design for the above mentioned stress ribbon footbridge based on an analytical plane rigid body model. But with increasing complexity of the structure analytical modelling becomes a challenging task. In this paper the potentials of using reduced finite element models for model-based design of active vibration control are investigated. For the example of the stress ribbon footbridge modal reduction is applied to a 2D and 3D finite element model. Results by means of the transfer behaviour between the actuator input and sensor output are compared to the existing experimentally validated analytical model and show good agreement. Hence, the reduced finite element models are suitable for model-based design of active vibration control. As proof, simulations show that the active vibration control delivers good results.

Keywords: footbridge dynamics; finite element model reduction; model-based design; multi-modal active vibration control

1. Introduction

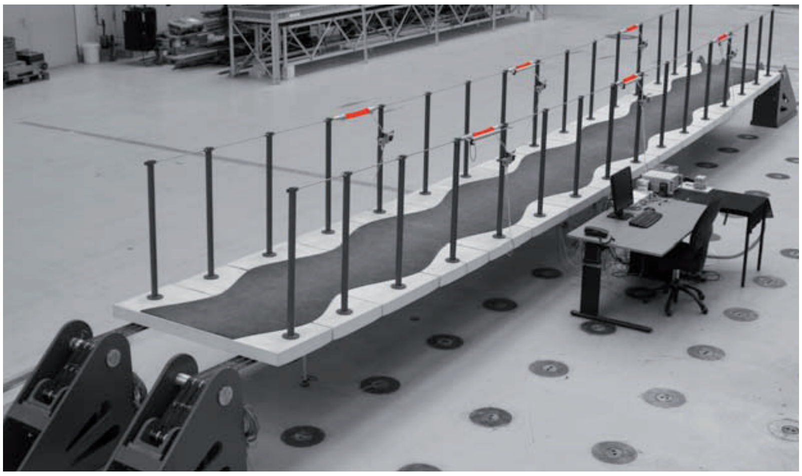

Fig. 1. Stress ribbon footbridge at the Technische Universität Berlin.

To investigate the efficiency of active vibration control (AVC) a 13 metre span stress ribbon footbridge with Carbon Fibre Reinforced Plastic (CFRP) ribbons was built in the laboratory of the Department of Civil and Structural Engineering at the Technische Universität Berlin [1], [2] (see Fig. 1). The developed AVC system consists of three pairs of pneumatic muscle actuators (PMAs) attached at handrail level in midspan and at the quarter-points of the bridge generating control forces and two displacement sensors monitoring the response of the bridge [3]. The multi-variable and multi-modal AVC allows the decoupled control of the first three modes. The controller design is based on an analytical plane rigid-body model approximation of the stress ribbon bridge, developed in [4]. With increasing complexity of the structure the development of an analytical model becomes a challenging task. For this reason, the potential of system identification was investigated in [5]. However, the above mentioned modelling approaches have their constraints. For analytical modelling the most critical are complexity and expenditure of time. System identification methods cannot be applied until the structure is built and consequently, model-based control design cannot be considered in early stage of development. For these reasons, this paper presents a method of deriving a model for model-based control design, using modal reduction of an existing finite element model (see Fig. 2).

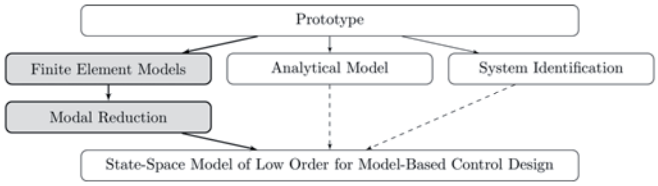

Fig. 2. Methodologies to obtain a reduced order model.

2. Results

Two finite element models of the stress ribbon footbridge with different degrees of freedom are investigated. By modal reduction, the number of degrees of freedom for both models is significantly reduced, preserving only vertical modes. The reduced order models are obtained in state-space description of modal form. Input and output matrices of the state-space models are determined according to actuator and sensor placement.

In simulation, the reduced finite element models are compared to the experimentally validated analytical model by means of the transfer behaviour in form of the amplitude frequency response (see Fig. 3). For all transfer functions, a good agreement between analytical model and reduced models is achieved.

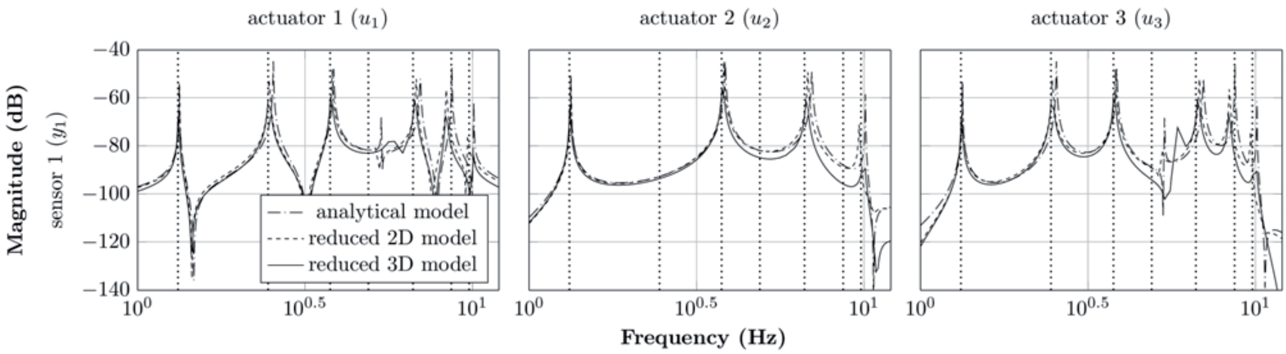

Fig. 3. The three diagrams illustrate the transfer behaviour between each of the three actuators and the first displacement sensor. The vertical dashed lines mark the eigenfrequencies of the real bridge.

The AVC simulations are performed with the analytical model as the true plant and an observer based on the reduced models, used to estimate the states. Results show, that the AVC works well for both reduced models.

To sum up, the efficiency of applying modal reduction to finite element models with a high number of degrees of freedom was demonstrated. The order of degrees of freedom was significantly reduced, still showing good agreement with the analytical model by means of the transfer behaviour. The AVC in simulation showed good results without the need of any adjustments.

In future work, modal reduction of detailed finite element models can be performed, preserving not only vertical but also horizontal and torsional modes. This will simplify the design of model-based active vibration control for more complex spatial structures.

3. References

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