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Dynamic Control of Adaptive Structures

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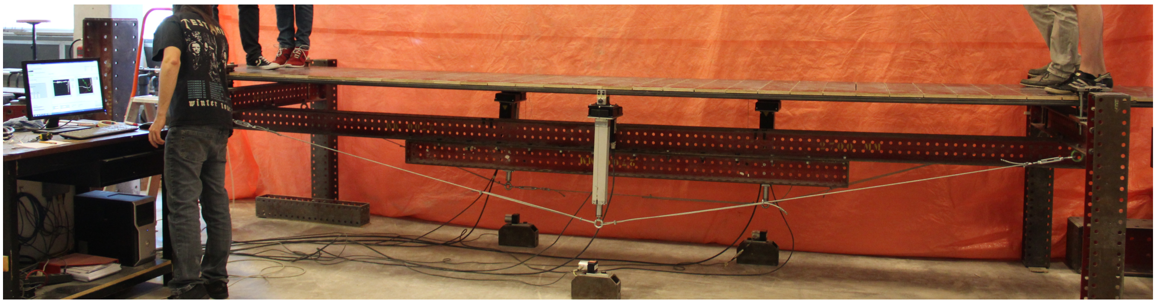


Figure 1: Experimental set-up of an adaptive pre-stressed truss structure

Introduction

In order to meet the high demands of modern society, buildings and their designs are getting more and more sophisticated in order to increase comfort and usability. Advances in technology, such as the implementation of active components, allow the structural engineer to increase the efficiency of the structure and to decrease the material and energy consumption significantly. In this work, the effects of such an active component on the dynamic response of a pre-stressed truss structure is compared with an equivalent passive design.

Actively Controlled Equations of Motion

The equations of motion of an actively controlled truss structure are shown in Equation 1. In this equation the external force of the actuator is not known a priory, since it is a function of the displacement and the velocity of the structure.

$$\mathbf{M}\ddot{\mathbf{x}}(t) + \mathbf{C}\dot{\mathbf{x}}(t) + \mathbf{K}\mathbf{x}(t) = \mathbf{F}_{ext}(t) + \mathbf{F}_{act}(\dot{\mathbf{x}}(t), \mathbf{x}(t), t) \qquad (1)$$

To account for the actuator forces, the equations of motion are rewritten in the State Space model of Equation 2. The State Vector for this case, is a combination of the position and velocity fields.

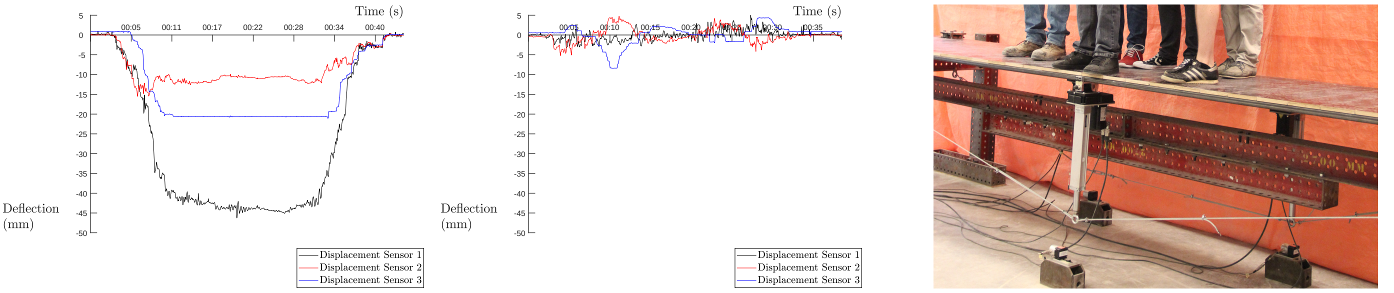
$$\begin{bmatrix} \dot{\mathbf{x}}_1(t) \\ \dot{\mathbf{x}}_2(t) \end{bmatrix} = \underbrace{\begin{bmatrix} \mathbf{0} & \mathbf{I} \\ -\mathbf{M}^{-1}\mathbf{K} & -\mathbf{M}^{-1}\mathbf{C} \end{bmatrix}}_{\mathbf{A}} \begin{bmatrix} \mathbf{x}_1(t) \\ \mathbf{x}_2(t) \end{bmatrix} + \underbrace{\begin{bmatrix} \mathbf{0} \\ \mathbf{1} \end{bmatrix}}_{\mathbf{B}} \mathbf{u}(t) \qquad (2)$$

In order to determine the dynamic response of the structure, an explicit Euler-Forward scheme is used, shown in Equation 3. In practice, this formulation has been extended towards a Runge-Kutta algorithm to maintain the numerical stability under larger time steps and more degrees of freedom. The results are validated with the commercial FEM-software package Abaqus.

$$\mathbf{x}_{i+1} = \mathbf{x}_i + \mathbf{A}\mathbf{x}_i\Delta t + \mathbf{B}\mathbf{u}_i\Delta t \qquad (3)$$

Experimental Study

Since the control laws used in the numerical approximations proved rather successful, a prototype of the truss structure has been built in the laboratory of the TU/e, which is shown in Figure 1. This design has been successfully tested on various loading scenario's, such as one or multiple walking point loads, step forces and impulses. Within the capacities of the actuators, the truss was able to reach the setpoints after some settling time within the accuracy of a few millimeters. A comparison with a passive truss has been made by locking the actuators in the position in which they compensate for the self weight of the structure, which is conventional from the field of structural engineering. When the structure is loaded by six people, the passive truss deflects three times the allowable amount, whereas the active truss is able to keep its deflection close to zero after some settling time.



(a) Passive truss (b) Active truss (c) Loading situation at a specific time instant (Active)

Figure 2: Comparison between a passive and an active structure, externally loaded by six people

MSc progress

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