Modelling and Simulation of the Nonlinear Vibrations of Axially Moving Long Slender Continua in Tall Host Structures

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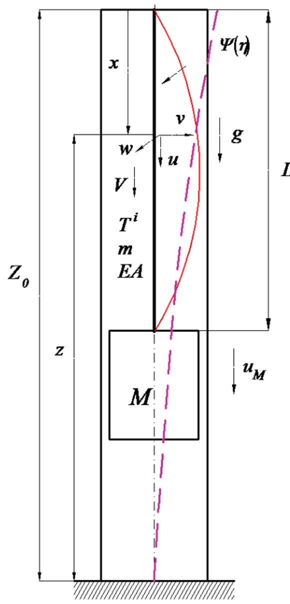
Abstract. Mixed Eulerian-Lagrangian rod finite elements are developed to simulate the transient dynamic behaviour of a suspension rope system of a high-rise elevator subjected to a harmonic sway of the host structure. The suspension cable is modelled as a Kirchhoff rod with full account for inertia, bending stiffness and the geometrically nonlinear coupling of transverse and axial vibrations. The time varying natural frequencies of the suspension system are compared against results available from the literature and primary system parameters are varied to conclude on their impact on the transient elevator operation. The model becomes particularly advantageous for large vibrations at or near the resonance.

Introduction

Lifting systems, such as cranes, mine or elevator hoists, feature axially moving ropes and cables, whose length vary during the operation. These axially moving slender continua with variable length exhibit a rich dynamic behaviour and are susceptible to parametric, self-excited or external excitations. Hence, proper design of such systems with regard to safety and comfort of operation or lifetime estimation requires an accurate mechanical model and a computationally feasible solution thereof.

Benchmark problem, computational model and its validation



We develop and validate a geometrically nonlinear finite element scheme for the transient simulation of a simple elevator model depicted in the figure on the right. It features an elevator cabin of mass M that is suspended by a single rope with time-variable length $L(t)$. The elevator is situated in a tall building structure that is assumed to sway harmonically in a cantilever bending mode $\Psi(\eta)$ due to wind loading, where $\eta = z/Z_0$ denotes the dimensionless vertical coordinate, counted from the ground level. The imposed building motion causes vibrations of the suspension system, whose response changes dynamically as the elevator car is moving in the hoistway.

The proposed finite element model of a Kirchhoff rod for the suspension cable features a variant of the Mixed Eulerian-Lagrangian kinematic description established in [1, 2]. The variable length of the suspension rope is taken into account by means of a hybrid (stretched) coordinate $\sigma \in [0, 1]$, with a spatially fixed (Eulerian) node at the entry to the domain and a material (Lagrangian) node at the elevator car. The present scheme numbers among the group of Arbitrary-Lagrangian-Eulerian methods, whose utility for the simulation of reeving systems is well recognised [3].

Traditional methods rely on the semi-analytical treatment of the governing system of partial differential equations by means of the Galerkin procedure using the eigenmodes of the axially moving continua as shape functions. They rely on some simplifying assumptions regarding the amplitude of oscillations or the coupling of transverse and axial vibrations. Specifically, in [4] and [5] different variants of the problem at hand based on the same geometric setup are investigated.

For a range of practical parameters, first, finite element simulations are compared against results available in the literature regarding the system's basic oscillatory response (frequency & amplitude), and, secondly, the influence of selected key parameters on the transient response of the elevator system is established.

References

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