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Vibration Control of Frame structure

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Abstract

The in-plane vibration analysis of frames connected at an arbitrary angle is performed using wave propagation method as proposed in [1]. The earlier work done by Mei in [1] and [2] were limited to frames having orthogonally connected members. In the present work, the procedure is extended for interconnecting members at an arbitrary angle. The wave propagation based method used in this work is computationally efficient compared to finite element method. Thus, optimal angular orientation of the intermediate member is found for minimal vibration transmission from the source to the target structure.

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*Keywords:*Wave propagation method; Finite Element Method, separated by semicolons; frames; optimization

1. Introduction

Planar frames comprise a wide variety of engineering structures. Many applications of frames have interconnecting members at an arbitrary angle. Though, numerical solution for such structures is routine, finding the exact solution for the vibration analysis of such frames is a challenging task.

Mei [1, 2] formulated the vibration analysis of such planar frames which considers the coupling effect of both transverse and longitudinal vibration with members connected at right angles. This approach uses wave propagation method for solving the equilibrium and continuity equation at the joint. In the present work, this approach is extended to frames which are connected at an angle. It is found that the wave approach is far more computationally efficient than Finite element Analysis as implemented in commercial software such as ANSYS. Owing to the

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efficacy of the wave-based approach, it can be used in structural optimization. In the present work, this is demonstrated for arriving at an optimal angular orientation between a one dimensional source and target structure. The objective in the optimization exercise is to minimize the vibration at the target structure for a point harmonic forcing applied at the source structure.

2. Wave Propagation Method

2.1. Governing Equations

Euler Bernoulli theory is used to model transverse vibrations and classical linear rod theory is used to model longitudinal vibration. The equations of motion for bending and longitudinal vibrations are

$$EI\left(\frac{\partial^4 y(x,t)}{\partial x^4}\right) + \rho A\left(\frac{\partial^2 y(x,t)}{\partial t^2}\right) = q(x,t) \tag{1}$$

$$\rho A\left(\frac{\partial^2 u(x,t)}{\partial t^2}\right) - EA\left(\frac{\partial^2 u(x,t)}{\partial x^2}\right) = p(x,t) \tag{2}$$

Where x is the position along the axis, t is time, $y(x,t)$ and $u(x,t)$ are transverse and longitudinal deflections, respectively, $q(x,t)$ and $p(x,t)$ are externally applied transverse and longitudinal forces, respectively, E and ρ are Young's modulus and density, respectively, I is the moment of inertia of the cross section, A is the cross-sectional area.

Suppressing harmonic time dependence ($e^{i\omega t}$), solution to equation (1) can be written as

$$y(x) = a_1^+ e^{-ik_1 x} + a_2^+ e^{-k_2 x} + a_1^- e^{ik_1 x} + a_2^- e^{k_2 x} \tag{3}$$

Where $k_1 = k_2 = \sqrt[4]{\rho A\omega^2/EI}$ (4)

$\mathrm{a}_1^+ =$ amplitude of propagating flexural wave in $+$ x direction
$\mathrm{a}_1^- =$ amplitude of propagating flexural wave in $-$ x direction
$\mathrm{a}_2^+ =$ amplitude of near field flexural wave in $+$ x direction
$\mathrm{a}_2^- =$ amplitude of near field flexural wave in $-$ x direction

Solution to equation (2) can be written as

$$y(x) = c^+ e^{-ik_3 x} + c^- e^{ik_3 x} \tag{5}$$

Where $k_3 = \sqrt{\frac{\rho}{E}}\omega$ (6)

$$c^+ = amplitude\ of\ propagating\ longitudinal\ wave\ in + x\ direction$$
$$c^- = amplitude\ of\ propagating\ longitudinal\ wave\ in - x\ direction$$

2.2. Propagation Matrix

Consider a wave moving from point A to B. If there is no discontinuity and there is a uniform structural element between these two points, the waves at these points are related by a propagation matrix as given in [1]. Waves at A and B are related as $b^- = f(x)a^-;\ b^+ = f(x)a^+$, where

$$f(x) = \begin{bmatrix} e^{-ik_1 x} & 0 & 0 \\ 0 & e^{-k_2 x} & 0 \\ 0 & 0 & e^{-ik_3 x} \end{bmatrix}$$