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Accuracy and Efficiency of Structural Theories for Free Vibration Analyses via Axiomatic/Asymptotic Method and Neural Networks

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Abstract: This paper presents novel approaches to investigate the accuracy and computational efficiency of 1D and 2D structural theories. The focus is on free vibration problems in metallic and composite structures. Refined theories are built via the Carrera Unified Formulation (CUF), and the influence of higher-order generalized variables is analysed via the Axiomatic/Asymptotic Approach (AAM). Best theory diagrams (BTD) are built by considering those models minimizing the computational cost and maximizing the accuracy. BTD can estimate the accuracy and efficiency of any structural models, including classical models and refined theories from literature. The construction of BTD can be a cumbersome task as multiple finite element (FE) problems are required. Machine learning through neural networks can significantly reduce such overhead. In other words, surrogate structural models are built using a limited number of FE analyses for training and having as input a structural theory and providing as output the natural frequencies without the need for finite element analyses. Finally, extensions to node-dependent kinematics (NDK) are presented for further optimization of the computational cost.

Keywords: structural dynamics, finite elements, structural theories, neural networks, CUF

1. Introduction

The use of refined structural theories is convenient to extent 1D and 2D theories to problems otherwise requiring 3D models [1, 2]. CUF has emerged as a powerful method to build any-order theories and related finite element matrices [3]. CUF exploits a few formal expressions and index notations to obtain unified governing equations independent of the order of the theory. Via CUF, classical and refined models can be implemented, and any non-classical effect considered, e.g., shear deformability, transverse stretching, and warping. The systematic use of CUF for 1D and 2D models leads to considerable reductions of computational costs estimable in 10-100 times fewer degrees of freedom than 3D FE.

The development of a refined structural theory requires the proper choice of higher-order terms. AAM has been introduced as a tool to select such terms [1]. AAM provides the Best Theory Diagram composed of those models minimizing the computational cost and maximizing the accuracy. BTD can estimate the accuracy and efficiency of any structural models, including classical models and refined theories from literature.

Via CUF, the structural theory can change point-wise, i.e., each node of the FE model can have a different structural model. Such a capability is referred to as NDK and is helpful to use refined models only where needed [4]. The combined use of CUF, AAM, NDK, and Neural Networks (NN) is a

promising approach to build surrogate models that can provide information on the structural theory and finite element discretization for a given problem [5].

2. Results and Discussion

The typical result provided by AAM is shown in Fig. 10, in which the horizontal axis is the error in computing the first ten natural frequencies, and the vertical axis reports the number of nodal degrees of freedom of various theories. The continuous line is composed of those theories with the minimum error for given DOF. Theories from literature are reported as well to evaluate their performances as compared to the best models. As well-known, third-order terms are very significant for this class of problems.

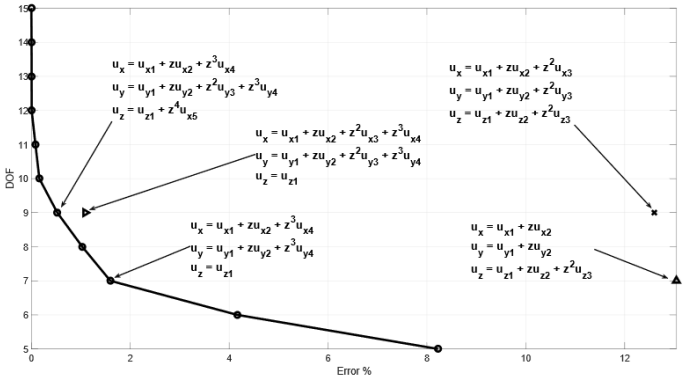

Fig. 1. BTD for first ten mode of a simply-supported shell with 0/90/0 lamination and a/h = 10.

3. Concluding Remarks

This paper has presented an overview of refined structural theories for structural dynamics problems. The focus is on methodologies to build and evaluate the role of refined terms and obtain the best theories with superior accuracy and computational efficiency. Furthermore, using machine learning algorithms is promising to obtain indications on how to build refined models and FE discretizations.

References

[1] PETROLO M, CARRERA E: Methods and guidelines for the choice of shell theories. *Acta Mechanica* 2020, **231**:395-434.

[2] CARRERA E, ELISHAKOFF I, PETROLO M: Who needs refined structural theories? *Composite Structures* 2021, **264**.

[3] CARRERA E, CINEFRA M, PETROLO M, ZAPPINO E: *Finite Element Analysis of Structures through Unified Formulation.* John Wiley & Sons, 2014.

[4] PETROLO M, CARRERA E: Selection of element-wise shell kinematics using neural networks. *Computers & Structures* 2021, **244**.

[5] PETROLO M, CARRERA E: On the use of neural networks to evaluate performances of shell models for composites. *Advanced Modeling and Simulation in Engineering Sciences* 2020, **7**.