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ON THE ROLE OF REFINED STRUCTURAL THEORIES TO IMPROVE THE COMPUTATIONAL EFFICIENCY OF NONLINEAR ANALYSIS OF COMPOSITES

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This paper presents an overview of the capabilities provided by refined 1D and 2D structural models to carry out nonlinear analyses of composites. 3D FEM is mandatory in many cases in which the complete stress field is necessary to predict the nonlinear behavior, e.g., failure analysis, progressive damage, residual stress and process-induced defects. Unfortunately, the aspect ratio constraints and small thickness of plies lead to prohibitive computational overheads. 1D and 2D models have less stringent constraints, but higher-order structural theories (HOST) are necessary to incorporate the full 3D stress field. Table 1 shows a comparison between HOST and 3D for various cases. The second column reports the ratio between the number of DOF of HOST and 3D; the third column shows the error of the least accurate model; the last column indicates the model with the best accuracy. For example, in the case of low-velocity impact on a bi-metallic plate, HOST requires 1% of 3D DOF, and it is more accurate than 3D as the latter has an error of 16%. This work presents the theoretical framework to obtain such reduced models and numerical examples on various nonlinear cases.

Table 1: Computational costs and accuracy of HOST and 3D

Problem	DOF HOST/3D	Error	Best Model
Three-point bending of a sandwich beam [1]	1 %	0 %	Same
Low-velocity impact on a bi-metallic plate [2]	1 %	16 %	HOST
Large deflections in cross-ply beams [3]	1 %	7 %	3D
Disbonding in sandwich beams [4]	24 %	1 %	3D
Curing of a composite part [5]	3 %	0 %	Same

References

[1] M.H. Nagaraj, I. Kaleel, E. Carrera, and M. Petrolo. Contact analysis of laminated structures including transverse shear and stretching. *European Journal of Mechanics - A/Solids*, 80:103899, 2020.

[2] M.H. Nagaraj, E. Carrera, and M. Petrolo. Progressive damage analysis of composite laminates subjected to low-velocity impact using 2D layer-wise structural models. *International Journal of Non-Linear Mechanics*, 127:103591, 2020.

[3] A. Pagani and E. Carrera. Large-deflection and post-buckling analyses of laminated composite beams by Carrera unified formulation. *Composite Structures*, 170:40 – 52, 2017.

[4] L. Qi, M.H. Nagaraj, E. Carrera, C.F. Gao, and M. Petrolo. Numerical analysis of disbonding in sandwich structures using 1d finite elements. *Composite Structures*, 252:112717, 2020.

[5] E. Zappino, N. Zobeiry, M. Petrolo, R. Vaziri, E. Carrera, and A. Poursartip. Analysis of process-induced deformations and residual stresses in curved composite parts considering transverse shear stress and thickness stretching. *Composite Structures*, 241:112057, 2020.