Layerwise mized elements with node-dependent kinematics for analysis of multilayered plates embedding composite and/or viscoelastic layers

10th International Conference DeMEASS2020
Design, Modelling and Experiments of Advanced Structures and Systems
Scopello, Italy, May 1-4, 2022

# On layerwise user-elements in Abaqus for free vibration analysis of variable stiffness composites and piezoelectric composite laminates

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**Summary**: In response to the still limited number of available literature on advanced structural models implemented as Abaqus user-elements, this study is devoted to the evaluation of layerwise user-elements for free vibration analysis of variable stiffness composites and piezoelectric composite laminated plates. The models predictive capabilities are demonstrated through a comparison with benchmark finite element solutions and 3D exact solutions.

## ABSTRACT

The multidisciplinary subject of smart composite structures finite element modelling, namely for the analysis of piezoelectric sensors and actuators integrated in composite laminates, has experienced a remarkable advent in terms of research in the last three decades, underlying the development of the next generation of smart and multifunctional structural systems. Additionally, the recent advances in automated manufacturing techniques have shed light on the capability of tailoring variable stiffness composites, with curvilinear fibre paths, to further improve the performance of the conventional straight fibre composites. However, the implementation of Abaqus user-elements (UEL), assigning refined structural models for the analysis of such multilayered structures, remains not fully unveiled.

Therefore, a family of layerwise user-elements in Abaqus is developed and validated for free vibration analysis of purely elastic variable stiffness composites - in the form of variable-angle tow laminates - as well as piezoelectric multilayered composite plates. For the analysis of purely elastic variable stiffness composite laminates, two layerwise user-elements, assigning the first-order shear deformation theory (FSDT) or the third-order shear deformation theory (TSDT), for three discrete layers, are compared with available finite element solutions in the literature. Both thin and moderately thick plates are considered, either simply supported or clamped. In the case of simply supported straight fibre composite laminates, the models accuracy assessment is carried out through a comparison with 3D exact solutions. On the other hand, for the two layerwise electro-elastic user-elements [1], each of the three discrete layers is described by a first-order shear deformation displacement field combined with a linear or quadratic $z$-expansion of the electric potential. The models predictive capabilities on the evaluation of the first twelve natural frequencies of laminated plates with surface bonded piezoelectric layers (PZT-4 or PVDF) are assessed by a comparison with 3D exact electro-elastic solutions for simply supported plates and native Abaqus solid elements.

Overall, the underlying numerical results demonstrate fairly accurate and computational efficient predictions of the lower natural frequencies and mode shapes.

**References**

[1] J.A. Moreira, F. Moleiro and A.L. Araújo (2021) Layerwise electro-elastic user-elements in Abaqus for static and free vibration analysis of piezoelectric composite plates. *Mechanics of Advanced Materials and Structures*. DOI: 10.1080/15376494.2021.18863812021.