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Exact Transfer- and Stiffness Matrix for the Composite Beam-column with Refined Zigzag Kinematics

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Abstract

The Refined Zigzag Theory (RZT), developed by Tessler/Di Sciuva/Gherlone is among the most promising approaches for analyzing shear-elastic composite structures today. Since its appearance many contributions have been published dealing with finite elements for laminated structures based on the efficient kinematic of RZT. For composite beam-columns C^0-elements of different orders as well as p-type approximations are formulated and assessed.

In this work a different approach is given. After establishing the governing equations in a first order differential equation system, the transfer matrix is obtained by a matrix series solution and by similarity transformation. The transfer matrix approach, in principle suited for 1D-structural elements such as beams, disks, circular plates and rotational shells, has been successfully applied in the past. Sometimes this approach exhibits numerical instabilities. The well-known relations between the transfer- and stiffness matrix are invoked to circumvent this drawback. The dynamic stiffness matrix and the load vector are obtained by reordering and partially inverting the submatrices of the transfer matrix. The results, which are obtained by one finite element only, are in agreement with available analytical and numerical solutions.

Keywords: Refined Zigzag Theory, Composite Beams, Finite Element Method, Transfer Matrix Method

1. Previous Research

Since the first fundamental work of Tessler et al. [1] in 2009, the Refined Zigzag Theory (RZT) has been implemented in different models for analyzing laminated composite and sandwich beams. The first approach given by Gherlone et al. [2] uses an C^0-element with anisoparametric shape functions. Oñate and co-workers [3] presented a linear isoparametric approach with reduced integration technique. Iurlaro [4] has given exact analytical shape functions for the static case. Di Sciuva et al. [5] presented a class of higher order elements in the framework of anisoparametric functions. Treviso et al. [6] introduce a complex stiffness formulation to address the problem of damping. Wimmer and Gherlone [7] recently give explicit matrices for the analysis of linear statics as well as stability and dynamics while Nallim et al. [8] demonstrate the usage of p-type shape functions. Further work on analytical solutions as well as corrections of zigzag functions is made by Gherlone [9, 10]. The modelling of delamination process has been presented by Eijo et al. [11]. Experimental assessment is reported by Iurlaro et al. [12]. Tessler [13] has derived a revised version of RZT based on Reissner's Mixed Variational Theorem labelled as RZT(m), whose main advantage over RZT is due to its superior prediction capability of transverse shear stresses. Referring to the mixed form of RZT Groh and Tessler [14] recently presented a low-order beam element with high efficiency in modelling the transverse shear stresses.

The objective of the present study is the generation of the transfer matrix method (TMM), sometimes labeled as state space method, with regard to the RZT. The TMM has the advantage that all main variables in particular stresses and stress resultants are obtained immediately by the solution process in the same accuracy while the displacement finite element method is known to be deficient and makes additional extensive smoothing strategies necessary. Laminated or composite beams have been studied by many authors. Using TMM Khedeir and Reddy [15] investigated the

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