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Koiter-Newton analysis of thick and thin laminated composite plates using a robust shell element

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Abstract

The Koiter-Newton method is a novel reduced-order modeling technique to efficiently trace the geometrically nonlinear equilibrium path of the structure in the presence of buckling. In this paper, the existing method is extended for nonlinear buckling analysis of thick and thin laminated composite plates. A 4-node quadrilateral element S4AT is developed as a geometric linear element in the co-rotational formulation of the Koiter-Newton method. The developed element S4AT is a combination of the membrane part and the plate-bending part. The quadrilateral area coordinate method is applied to make the element insensitive to the mesh distortion. The Reissner-Mindlin laminated composite plate theory is used to consider the transverse shear deformation effect, and the shear-locking phenomenon is eliminated using the Timoshenko laminated composite beam theory. The performance of the method in terms of reliability, accuracy and computational effort is demonstrated with several examples.

Keywords: Koiter-Newton method, Nonlinear buckling, Thick and thin laminated composite plate, Quadrilateral area coordinate method, Transverse shear deformation, Timoshenko laminated composite beam theory

1. Introduction

Thick and thin laminated composite plates are prone to exhibit obviously geometric nonlinearities in the presence of buckling. The standard technique for the nonlinear structural analysis is the Newton iteration based path-following method in the framework of the finite element analysis [1–3]. However, the high computational complexity generated from the full nonlinear analysis is still a decisive cost factor on modern computers.

Some reduced-order modeling techniques [4–7] based on Koiter asymptotic analysis have become computational less expensive alternatives. Since the classical Koiter's asymptotic expansion [8] is applied only once at the bifurcation point, the initial post-buckling path in a small range of the expansion point can be obtained using the above Koiter approaches, which limits a wider application. Recently, a new hybrid reduced-order modeling technique, termed the Koiter-Newton method (KN) [9, 10], has been proposed to achieve the entire equilibrium path in a step by step manner. The basic premise behind the proposed approach is to use Koiter's asymptotic expansion at any equilibrium point from the beginning of the equilibrium path, rather than to use it only at the bifurcation point as done in former Koiter approaches. In each incremental step, the method combines a prediction phase using a nonlinear reduced order model(ROM) based on improved Koiter asymptotic expansion with a Newton iteration based correction procedure, thus allowing the algorithm to use fairly large step sizes. The bifurcation branches lying before the limit point can be detected efficiently by a bifurcation indicator, which is also often used in asymptotic-numerical methods [11, 12] and arc-length methods [3]. Another merit of the method is that it can be easily achieved in the finite element (FE) environment. Both the co-rotational formulation [13] and the *von Kármán* kinematics [14] are respectively used in the FE implementation of the proposed method. The plate elements used in the previous work [13, 14] are isotropic quadrilateral elements based on the classical plate theory. Due to the limitation related to the element type, the current method can only analyze the thin isotropic plates with rectangular meshes. In this contribution, a linear flat shell element is designed in the co-rotational (CR) formulation for the Koiter-Newton method to do the geometrically

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