Buckling and post-buckling analysis of the delaminated composite plates using the Koiter-Newton method

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Abstract

The Koiter-Newton method has been proved to be a computationally efficient method for buckling and post-buckling analysis of structures, using a novel reduced-order modeling strategy. In this paper, the existing method is extended for laminated composite plates with delamination. We develop a 4-node quadrilateral element S4DE as a geometric linear element in the co-rotational formulation of the Koiter-Newton method. The assumed layerwise displacement model of the developed element is enriched with Heaviside unit step functions to model delamination. The displacement fields of each layer are described using the superposition of first-order shear deformation and layerwise functions. The zig-zag theory is applied to enhance the numerical accuracy and computational efficiency of the developed element. The construction of the reduced order model requires derivatives of the strain energy with respect to the degrees of freedom up to the fourth order, which is two orders more than traditionally needed for a Newton based nonlinear finite element technique. The geometrical nonlinearities are taken into account using derivatives of the local co-rotational frame with respect to global degrees of freedom. Various laminated plates with different thicknesses, delamination lengths and stacking sequences are considered to validate the good performance of the present method in terms of numerical reliability, accuracy and computational effort.

Keywords: Koiter-Newton method, Buckling and post-buckling, Delamination, Layerwise displacement model, Reduced order model

1. Introduction

Laminated composites are widely used in a variety of engineering applications due to their very high strength-to-weight and high stiffness-to-weight ratios [1–3]. With the use of composite materials, however, certain new material imperfections can be encountered. One of major imperfections is delamination, which is a predominant form of damage phenomenon in laminated composites. The presence of delamination in composite laminates can reduce the overall stiffness and cause the material unbalance in a symmetric laminate. This may significantly lower the load-carrying capacity of the compressively loaded structures, particularly in the presence of buckling [4–7]. Therefore, great research interests have been generated to study the effect of delamination on the load-carrying capacity of the composites.

Generally,the laminated plate theories can be distinguished as either equivalent single-layer theories (ESL) or layerwise theories [8]. For the past two decades, analytical and numerical methods have been proposed by many researchers to investigate the buckling and post-buckling behavior of delaminated composite structures, based on the above two major theories. The equivalent single-layer theories include classical laminate plate theories (CLPT), first-order shear deformation theories (FSDT) and higher order shear deformation theories (HSDT). Kardomateas et al. [9] have adopted a one-dimensional beam-plate model to study the effect of transverse shear on buckling and post-buckling of delaminated composites. Chen [10] has investigated transverse shear effects for compressive delamination buckling using the variational energy principle. Buckling analysis of delaminated laminates has been performed by Hu [11] with consideration of contact in buckling mode using the finite element method (FEM), based on the Mindlin

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