Engineering Analysis with Boundary Elements 35 (2011) 818–826

Contents lists available at ScienceDirect

Engineering Analysis with Boundary Elements

journal homepage: www.elsevier.com/locate/enganabound

Bending and vibration responses of laminated composite plates using an edge-based smoothing technique

X.Y. Cui [a], G.R. Liu [b], G.Y. Li [a,*]

[a] State Key Laboratory of Advanced Design and Manufacturing for Vehicle Body, Hunan University, Changsha 410082, PR China
[b] School of Aerospace Systems, University of Cincinnati, Cincinnati, OH 45221-0070, USA

ARTICLE INFO

Article history:
Received 23 November 2009
Accepted 16 December 2010
Available online 25 February 2011

Keywords:
Numerical methods
Vibration
FEM
Techniques-FEM
Laminated composite plates

ABSTRACT

In this paper, bending and vibration analysis of laminated composite plates is carried out using a novel triangular composite plate element based on an edge-based smoothing technique. The present formulation is based on the first-order shear deformation theory, and the discrete shear gap (DSG) method is employed to mitigate the shear locking. The smoothed Galerkin weak form is adopted to obtain the discretized system equations, and edge-based smoothing domains are used for the numerical integration to improve the accuracy and the convergence rate of the method. The present formulation is coded and used to solve various example problems of bending and free vibration of laminated composite plates. It is found that the present method can provide excellent results with a wide range of thickness and is free of shear locking.

1. Introduction

The bending and vibration analysis of laminated composite plates has become more and more important in the past several decades, due to rapidly increased application of composite materials in structure systems in civil, mechanical and aerospace engineering. The search for simple, efficient and inexpensive numerical methods applicable to both thin and thick laminated composite plates has been receiving much interest. Various laminated plate theories have been introduced for analysis of thin to thick laminated plates such as the classical laminated plate theory (CLPT), the first-order shear deformation theory (FSDT) and the higher-order shear deformation theory (HSDT) [1]. Using these theories, some existing numerical methods have been adopted to compute bending deformation and natural frequencies of composite laminates. Reddy [2] developed the free vibration analysis of antisymmetric, angle-ply laminated plates including transverse shear deformation using the finite element method. A 3-node higher-order triangular plate element TRIPLT was formulated by Lakshminarayana and Murthy [3]. This element has 15 degrees of freedom (DOF) containing displacements and rotations along with their first derivatives per node. Noor and Burton [4] gave an assessment of computational models for multilayered anisotropic plates. Dai et al. [5] studied the static and free vibration analysis based on HSDT using element free Galerkin (EFG) method. Setoodeh and Karami [6] investigated the characteristics of anisotropic thick laminated composite plates using a 3-D layer-wise FEM. Lee and Han [7] developed a 9-node assumed strain element for free and forced vibration analysis of laminated composite plates and shells.

Although large numbers of laminated plate elements have been developed, most of them have a complex form. Displacement-based triangular elements have a very simple form as they only consider the displacement and rotation degrees of freedom at nodes and without additional parameters. However, these elements generally have a low accuracy because of the inherent characteristic of overstiff phenomenon from the standard weak formulation. In order to "soften" the system and allow the use of discontinuous shape functions, Liu [8] proposed a general formulation of smoothed Galerkin weak form using the strain smoothing technique [9]. Efficient numerical methods have been developed based on both FEM and meshfree settings using different smoothing domains that can be node-based cell-based can edge-based. Using the point interpolation method and the node-based smoothing operations, a node-based smoothed point interpolation method (NS-PIM) were developed using polynomial basis functions (NS-PIM [10]) and radial basis functions (LC-RPIM [11]). Liu and Zhang [12] proved that the NS-PIM is variationally consistent, and can provide much better stress results. More importantly it can provide upper bound solution in energy norm. Liu et al. [13] has found that the LC-RPIM needs a high order interpolation to obtain satisfactory solutions for laminated composite plates. However, the node-based smoothed models are "overly-soft", which leads to temporal instability [14–16]. The instability can be clearly shown as spurious non-zero energy modes

* Corresponding author. Tel.: +86 731 8821717; fax: +86 731 8822051.
E-mail address: gyli@hnu.cn (G.Y. Li).

0955-7997/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enganabound.2011.01.007