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A global–local theory with stress recovery and a new post-processing technique for stress analysis of asymmetric orthotropic sandwich plates with single/dual cores

M. Shariyat*, S.M.R. Khalili[1], I. Rajabi

Faculty of Mechanical Engineering, K.N. Toosi University of Technology, Tehran 19991-43344, Iran

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Abstract

While the 3D elasticity and the available local and zigzag theories encounter inaccuracies for very thin plates, results of the global theories become unreliable for thick plates with severe transverse variations in the material properties. In the present research, a quadratic finite element global–local sandwich plate theory with elasticity correction (stress recovery) is proposed for static stress and displacement analysis of sandwich plates with orthotropic face sheets and single or dual cores. Since the transverse shear stresses are derived based on the three-dimensional theory of elasticity, the continuity condition of the transverse shear stresses is satisfied at the interfaces between the layers, a priori. The presented theory not only leads to higher accuracies in comparison to the available high-order zigzag theories in some cases (especially, for soft or dual cores) but also it is computationally more economic. Results show that the results of the available zigzag and global–local theories may encounter inaccuracy problems not only for huge numbers of the sub-layers, but also for small numbers of the orthotropic layers.

Keywords: Stress analysis; Sandwich plates; Single and dual cores; Finite element analysis; Global–local theory; Stress recovery

1. Introduction

In contrast to the traditional multilayer structures, the sandwich plates may be composed of layers fabricated from quite different material properties; so that the resulting structure may consist of very soft as well as very stiff layers or it may include layers with quite different material characteristics (homogeneous isotropic, FGM, viscoelastic, orthotropic, piezoelectric, etc.) in a single construction. Therefore, the resulting structure takes full advantages of all

* Corresponding author. Tel.: +98 9122727199; fax: +98 21 88674748.
E-mail addresses: m_shariyat@yahoo.com, shariyat@kntu.ac.ir (M. Shariyat), smrkhalili2005@gmail.com (S.M.R. Khalili).
URL: http://wp.kntu.ac.ir/shariyat/publications.html (M. Shariyat).
[1] Tel.: +98 21 8406 3208; fax: +98 21 88677273.

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the unique features of the materials of the individual layers. This distinguished advantage of the sandwich plates, which enables meeting different and sometimes opposite design criteria, has encouraged using them in traditional as well as modern and high-tech engineering structures. Apart from the in-plane stresses, prediction of the transverse stresses at the interfaces between layers is often an important issue [1]. When there are discontinuities in the material properties of the adjacent layers, the transverse shear and normal stresses induced in the bonding materials between the layers may be extremely important, especially when differences between the material properties of the adjacent layers are significant. In contrast to the common knowledge, the core is not necessarily fabricated from softer materials; in some applications, it may constitute the main load carrying element of the structure whereas the face sheets may play a protective role.

Since the thickness of the sandwich plates is often greater than that of the laminated composite plates and the transverse distribution of the material properties commonly experiences serious jumps at the interfaces between the layers, the traditional equivalent single layer (ESL) theories (the so-called global theories) such as the classical plate theory (CLT), first-order shear-deformation theory (FSDT), and even the higher-order shear-deformation theories (HOSDT) [2–5] may not lead to accurate results in many cases, including cases wherein the core is fabricated from very soft materials or foams or number of the layers is large. Even separating the bending and shear components of the displacements may not improve the situation [6]. To overcome these shortcomings, a number of layerwise plate theories [2,7–12] have been proposed to account for local variations of the displacement components. These plate theories are more accurate as they are capable of tracing details of local variations of the in-plane displacement components within each layer in the transverse direction. However, since the transverse stress continuity condition has not been included a priori in these theories, they allow discontinuities in the transverse stresses at the interfaces between the layers. The other main disadvantage of these theories is that number of the unknown displacement parameters grows with the number of the layers.

To retain advantages of the equivalent single-layer as well as layerwise theories, a new type of plate theories called zigzag theory has been proposed [13–17]. Di Sciuva [7,18] pioneered these models by using linear zigzag functions which account for piecewise linear transverse distributions of the in-plane displacement components and a priori satisfy the continuity of the displacements and transverse shear stresses at interfaces. Di Sciuva [19] was the first researcher to correct results of the zigzag theories through determination of the interlaminar shearing stresses by integrating the local elasticity equilibrium equations. Later, Di Sciuva [20] extended the theory by superposition of the linear zigzag distribution to a smeared cubic global one. Tessler et al. [21] have proposed a refined zigzag theory (RZT) wherein, description of the in-plane displacements of the FSDT was improved by adding a transverse piecewise linear zigzag function. They claimed that although the formulation has not enforced the continuity condition on the transverse shear stresses among the adjacent layers, it was robust. Recently, Iurlaro et al. [22] and Gherlone [23] presented comparative studies for assessment of the refined zigzag theories. Comparing results of the two main types of the zigzag functions, i.e., Murakami's zigzag function and the refined zigzag function of Tessler, Gherlone, and Di Sciuva [7,18–22], Gherlone [23] concluded that in many cases, Murakami's zigzag function either cannot be used or may lead to erroneous results; because Murakami's zigzag function appears to be geometry-based rather than material-based and does not satisfy the continuity of the transverse shear stresses. Furthermore, Murakami's zigzag function requires using C^1-continuous finite elements for the transverse deflection variable and diminishes the transverse shear stresses erroneously along the clamped boundaries. Liu [24] extended concepts of the zigzag theory through introducing the double superposition concept.

Only limited layerwise and zigzag theories have considered the continuity condition of the transverse stresses at the interfaces between the layers [7,18–20]. These types of theories are the most appropriate for the analysis of the sandwich plates; since interfacial failures due to the discontinuity in the transverse shear stresses at the interfaces are more likely in these plates in comparison to the laminated composite plates. Carrera's unified formulation (CUF) is a general framework that may be used for different global (equivalent single-layer), local (layerwise), and zigzag kinematic descriptions of the displacement components in the face sheets and cores [5]. This unified formulation especially leads to accurate results when used in a mixed formulation form; due to satisfying the continuity condition of the transverse stresses at the interfaces between the layers. Khalili et al. [5] have successfully employed this formulation for non-linear dynamic analysis of a sandwich beam with pseudoelastic SMA hybrid composite face sheets.

Although the three-dimensional elasticity approach and the layerwise theories (among them the zigzag theories) are known to lead to more accurate results, some well-known researchers have proven that accuracy of these theories may