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Shear buckling of sandwich plates – Incompressible and compressible cores

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ABSTRACT

Shear buckling behavior of sandwich panels with an incompressible and a compressible core is presented. The mathematical formulation includes various formulations for layered sandwich panel such as: Ordinary Sandwich Panel Theory (OSPT), High-Order Sandwich panel Theory (HSAPT) without in-plane core rigidity and with in-plane rigidity (HSAPT-A) Theory. The various models are based on a variational approach that yields the non-linear field equations and the appropriate boundary conditions. The high-order model that takes into account the in-plane rigidity through the depth of the core, denoted as HSAPT-A, uses the accurate solution of the 3D elasticity problem involved. Linearization is achieved using a perturbation technique which yields equations for the pre-buckling and buckling stages along with the appropriate boundary conditions. A Galerkin solution type is adopted for all models and a closed-form solution through the depth of the core is used for the high-order case where the core rigidity is considered. A numerical study of a simply-supported panel with various layouts and dimensions and subjected to in-plane shear load is conducted. The results include bifurcation loads and mode shapes (3D or contour plots) of the displacements, internal stress resultants and interfacial stresses at face–core interfaces.

1. Introduction

Sandwich panel serves as principal and secondary structural member components in various applications in the aerospace, transportation and civil engineering industries. In general, modern sandwich panels consist of two metallic or laminated composite face sheets and a core made of low strength and low weight materials such as foam, balsa wood or honeycomb made of metal or nomex (paper). The introduction of low strength foam core is associated with deformation through the depth of the core, in the out of plane (vertical) direction, that causes a non-linear shape of its section plane and its thickness is not preserved under loading. These deformations are accompanied by large vertical normal stresses as well as high shear stresses that must be accounted for. In general, the low strength core has some in-plane rigidity but its contribution to the overall response of the sandwich panel is minor due to the couple contribution of the face sheets and usually it is neglected. Notice, that in case of a metallic honeycomb core its vertical rigidity is very large which preserves the thickness of the core, i.e. in-compressible core.

In general, sandwich panels are subjected to various loading schemes, such as in-plane or out of plane loads and maybe associated with small or large displacements. The introduction of in-plane loads, compressive or shear, may be associated with large displacements that are non-linear in general and may lead to loss of stability.

Solid panels subjected to shear loads have been in use for many years in the aviation and transportation industries. In such cases the loss of stability is of great concern and in general is associated with large displacements and wavy patterns. However, in the case of a typical modern sandwich panel, with a foam core, there is a contribution of the flexible foam core that interacts with the wavy pattern. The major goal of the paper is to demonstrate the effects of the compliant core on the buckling responses, due to its core vertical flexibility and its in-plane rigidity when in-plane shear loading scheme is applied at the edges of the panel, see Fig. 1. The study ahead describes the loss of stability of sandwich panels with incompressible and compressible cores within the framework of various geometrical parameters and compares it with various well known classical computational models.

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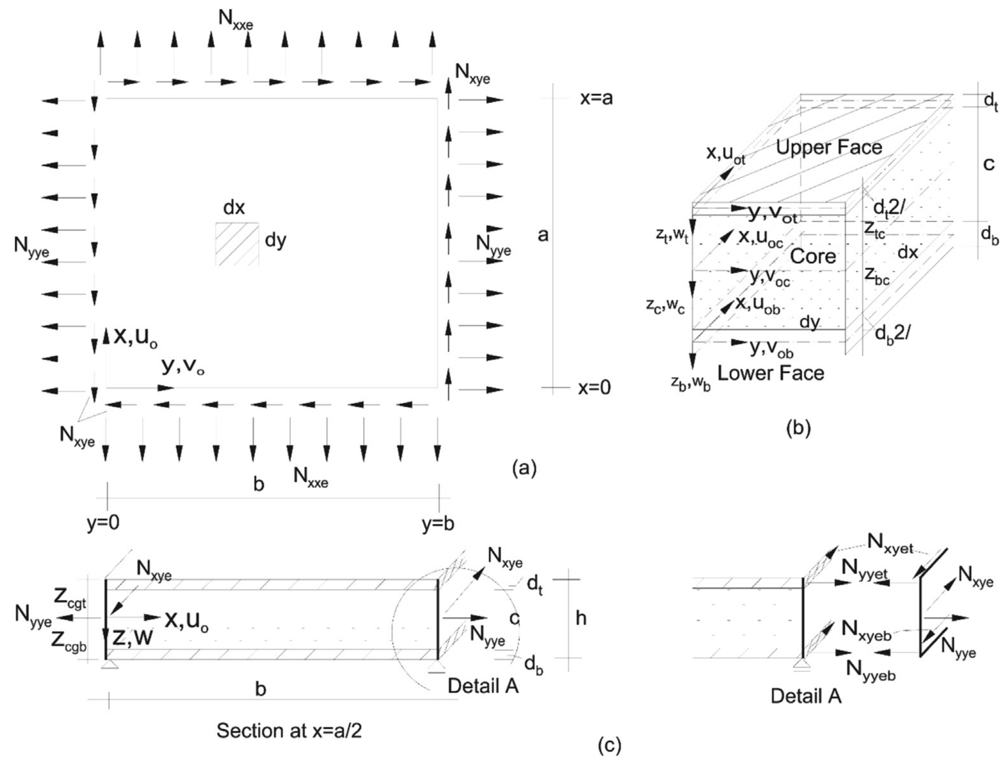

Fig. 1. Geometry, loads, coordinates and typical details of edge beams of a sandwich plate.

In general the response of sandwich panel response based on the core involved can be described by: incompressible (metallic honeycomb) or compressible (foam, low strength honeycomb and similar). The classical works in the field of sandwich panel are limited to incompressible core since for many years the only cores used were metallic honeycomb. In general in this case the core is assumed to be infinitely rigid in the vertical direction and the section plane is assumed to remain plane due to loading. The classical references include for example, Refs. [1,19,30,26] and others. Recently, within the framework of incompressible core, there are some new works that assume that the section plane displacements include also a trigonometric function, such as Refs. [31,32] and similarly, Refs. [24,25]; that in addition to the trigonometric functions used a combination of bending and shear deformations, similar to Allen splitted rigidities approach [1]. The other approach is the high-order approach that assumes that the sandwich panel is a layered structure with a compressible work see for example, Ref. [7] and many others.

Instability, in general, of sandwich structures is described by two types of deformations, overall buckling – where the two face sheets move in the same direction and local bending of the face sheets associated with a large number of half waves (wrinkling) modes, see text books mentioned previously as well as Refs. [6,5]. This decoupling of modes leads to an approach where the wrinkling mode is determined by two isolated face sheets that rest on elastic foundation which is provided by the vertical rigidity of the core and they do not interact, see Ref. [27]. The overall buckling is determined through a concept that replaces the actual layered panel with an equivalent single layer (ESL), see Refs. [16,21]. These approaches are erroneous or incorrect when sandwich panels with compliant cores are considered. In such panels the global and the local buckling mode interacts, as well as collaboration between the two face sheets, thus the critical mode may shift from a global mode to a local one and vice versa or a combination of the two.

The decoupling mode approach has led to a group of research works that describe the buckling response through superposition of vertical symmetric and asymmetric or a combination of specific modes, see Refs. [3,18,12,13,29]. This approach is limited to specific construction layout and specific boundary conditions. A different approach based on an elastic foundation approach with two parameters that yields only wrinkling modes has been adopted by Briscoe et al. [4]. A high-order theory approach used by Kant and Patil [14] replaced the layered sandwich panel with an equivalent high-order shear deformable plate but it is unable to determine the local buckling modes within the overall behavior. A large number of research works deal with the problem using general approaches such as: energy methods, see Refs. [28,15,11] or finite elements methods, see Refs. [17,2,20].

A different systematic rigorous approach that uses the high-order approach, see Ref. [9]; does not decouple the modes and follows the non-linear HSAPT model, see Ref. [7].

The present analysis uses the HSAPT approach for plate with a compressible core, see Refs. [8,9] and the OSPT model for the incompressible core, see Ref. [10]. Both computational models are based on variational principles that yield the non-linear field equations along with the appropriate boundary conditions. The equations for the pre-buckling and the buckling stages are derived using a perturbation technique, see Ref. [22].

The assumptions used here follow those of the HSAPT model, see Refs. [7,8,9] where the deformations of the face sheets are large, with moderate rotations while the core is assumed to undergo large displacements but with kinematic relations of small displacements, since a significant part of these deformations are rigid body motions that are not associated with in-plane stresses. In general, it is assumed that the layered sandwich panel consists of two linear elastic face sheets that are modeled as ordinary thin plates with in-plane and bending rigidity and a three dimension linear elastic core with vertical shear and vertical normal stresses and a negligible in-