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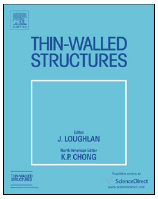

Full length article

Buckling of a standing corrugated sandwich plate subjected to body force and terminal load

Fei-Hao Li[a,b], Bin Han[a,c,d,*], Qian-Cheng Zhang[a,b], Feng Jin[a,b], Tian Jian Lu[a,b,*]

[a] MOE Key Laboratory for Multifunctional Materials and Structures, Xi'an Jiaotong University, Xi'an 710049, PR China
[b] State Key Laboratory for Strength and Vibration of Mechanical Structures, Xi'an Jiaotong University, Xi'an 710049, PR China
[c] School of Mechanical Engineering, Xi'an Jiaotong University, Xi'an 710049, PR China
[d] School of Engineering, Brown University, Providence, RI 02912, USA

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ABSTRACT

The global buckling behavior of a vertically standing corrugated sandwich plate subjected to body force and terminal load is analyzed through an improved first order zig-zag shear deformation theory, with the transverse shear effect of face sheets taken into account. When the face sheets are relatively thick and/or the sandwich plate has relatively large thickness to height ratios, the transverse shear effect of the face sheets affects significantly the critical buckling load. The effect becomes more obvious when body force rather than terminal load is applied on the clamped plates. The influence of geometric parameters on critical buckling parameters is also explored.

1. Introduction

Sandwich plates with periodic lattice cores, either two- or three-dimensional, possess superior bending stiffness, strength and shock resistance with respect to monolithic plate of the same mass. They also present opportunities for additional functionalities, such as energy absorption, active cooling and vibration/noise control. In particular, due to simple fluid-through topology and relatively easy fabrication, corrugated sandwich plates have enjoyed widespread applications in areas of packaging, building construction and high-speed railway transportation [1,2]. Recently, it has been envisioned that corrugated sandwich plates are attractive candidate for constructing oversized lightweight structures with multi-functionalities, such as large-scale gates and towering walls. In practice, when such a large structure exhibits accelerated movement, its self-weight or acceleration-induced body force as a kind of in-plane distributed load can play an important role in affecting its stability and natural frequencies. Considering the effect of body forces is therefore necessary in the stability analysis and design of a standing plate especially when it has relatively large scale.

Existing theoretical studies on the buckling and vibration behaviors of standing monolithic or laminated plates subjected to body forces are mainly carried out with the classical plate theory or the Mindlin plate theory. Considering the effect of body forces, Sussaman and Wang [3] studied the elastic stability of a simply-supported thin rectangular plate under linearly variable compressive stresses. Brown [4] investigated the elastic buckling behavior of plates with a variety of boundary conditions under three different distributions of in-plane loading. Using the Levy and Ritz method, Wang et al. [5,6] solved the gravity-induced buckling problem of a standing vertical plate under several boundary conditions.

Apart from body forces, the influence of top (terminal) load and plate aspect ratio (e.g., ratio of width to height) on the buckling performance of standing plates have been explored. For instance, based on the Mindlin plate theory, Bodaghi and Saidi [7] presented an exact analytical solution for the stability of a vertical moderately thick laminated plate subjected to self-weight and top load.

In addition to buckling, Fauconneau and Marangoni [8], Yu and Wang [9,10] demonstrated that self-weight affects considerably the natural frequency and mode shape of a standing heavy plate.

Existing theories for modeling the displacement fields and characterizing the buckling/vibration behaviors of laminated composite plates and sandwich plates include: the classical theory, the higher-order equivalent single layer theory, the zig-zag theory, the layerwise theory, and the mixed theories [11,12]. These theories differ mainly in the shape functions of shear deformation and the modeling of interlaminar continuity stresses. Up to now, the global buckling analysis of standing corrugated sandwich plates subjected to in-plane distributed load is yet studied. Further, most existing theories assume that the face sheets of sandwich plates are thin and hard so that their shear effect can be ignored [13,14]. Recently, Krzysztof et al. [15] developed a seven-layer sandwich beam model and found that the shear deformation of face sheets should be taken into account when the sandwich core is

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[*] Corresponding authors at: MOE Key Laboratory for Multifunctional Materials and Structures, Xi'an Jiaotong University, Xi'an 710049, PR China.
E-mail addresses: hanbinghost@mail.xjtu.edu.cn (B. Han), tjlu@mail.xjtu.edu.cn (T.J. Lu).

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relatively soft.

The buckling behavior of a vertical corrugated sandwich plate under body force and/or terminal load remains to be explored. Relative to a monolithic or laminated plate of equal mass, the corrugated sandwich plate may be more stable because of its in-plane orthotropic mechanical property and excellent flexural rigidity, especially when the main bending direction is coincident with the in-plane loading direction. This study aims to address the issue by employing the first order shear deformation theory and the improved zig-zag formulation [16] to describe the kinematics of the corrugated sandwich plate subjected to different combinations of boundary constraints (e.g., free, simply supported and clamped). During the analysis, the corrugated core is modelled as an equivalent orthotropic layer. Different from previous studies on similar problems, the proposed displacement field takes the shear effect of face sheets into account. The principle of minimum total potential energy and the p-Ritz method are employed to solve the global buckling problem. The theoretical predictions are validated by comparing with existing results when the sandwich plate is degenerated to a monolithic plate as well as finite element simulation results when the corrugated sandwich plates are of concern. The influence of face sheet shear effect on critical buckling loads is quantified for face sheets made of metal, functional graded material (FGM) and carbon fiber-reinforced composite (T700/3234). The effects of face sheet thickness, core relative density, corrugation inclination angle, and sandwich plate aspect ratio are also explored.

2. Formulation

2.1. Problem definition

With reference to Fig. 1a, consider the global buckling behavior of a vertically standing corrugated sandwich plate of width W and height L subjected to both gravitational force and terminal load. Let $a = W/L$ define the aspect ratio of the sandwich plate, and let the Cartesian coordinate system be located at the geometrical center of the plate. Fig. 1b depicts the geometric parameters of the sandwich cross-section: total thickness h, core height c, face sheet thickness t_f, core plate thickness t_c, and corrugation inclination θ. The terminal load P is applied at the center line of the top cross-section, while the gravity G is exerted on the whole sandwich structure.

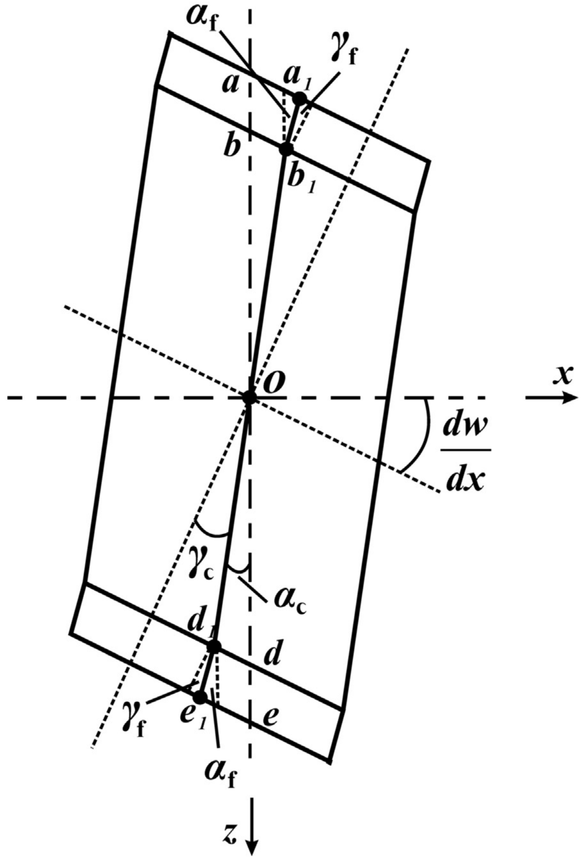

Fig. 2. Displacement hypothesis of improved zig-zag form (x-z plane).

2.2. Kinematics

The present study treats the discrete corrugated core of Fig. 1b as an equivalent uniform orthogonal layer. Then, based on the first order shear deformation theory and the improved zig-zag formulation [16], Fig. 2 presents the displacement hypothesis for the sandwich with equivalent core. Upon deformation, the straight line *abode* originally perpendicular to the mid-surface moves to a new position $a_1b_1od_1e_1$. Let α_c and α_f represent the rotation angle of the core and the face sheets in

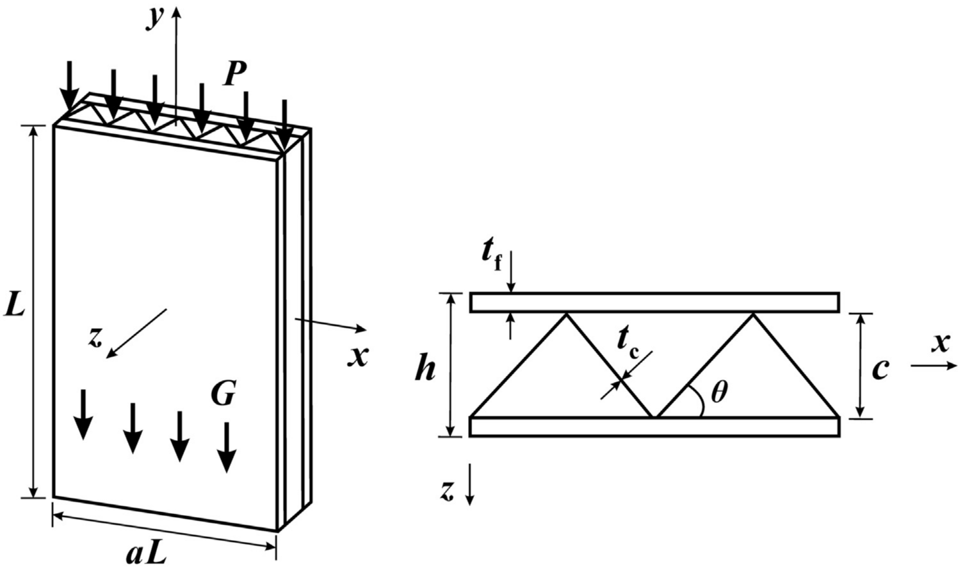

Fig. 1. (a) A vertically standing corrugated sandwich plate under combined body force and terminal load; (b) cross-sectional view of corrugated sandwich.