Composite Structures 150 (2016) 181–190

Contents lists available at ScienceDirect

Composite Structures

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

Bending of the composite lattice cylindrical shell with the midspan rigid disk loaded by transverse inertia forces

A.V. Lopatin [a], E.V. Morozov [b,*], A.V. Shatov [a]

[a] Department of Aerospace Engineering, Siberian State Aerospace University, Krasnoyarsk, Russia
[b] School of Engineering and Information Technology, University of New South Wales at the Australian Defence Force Academy, Canberra, Australia

ARTICLE INFO

Article history:
Received 18 March 2016
Accepted 2 May 2016
Available online 3 May 2016

Keywords:
Spacecraft tubular body
Composite lattice cylindrical shell
Bending analysis
Finite-element analysis
Transverse inertia loading
Semi-membrane shell theory

ABSTRACT

Bending deformation of a composite lattice cylindrical shell with the rigid disk attached at the midspan is studied in this paper. The shell with the disk is subjected to a transverse inertia load. The problem is solved using a continuum model of the lattice structure and equations of the semi-membrane theory of orthotropic cylindrical shells. The shells with two variants of the end supports are analysed. Analytical formulas providing the tools for fast and accurate calculations of the transverse disk displacement are derived. Based on these solutions, a parametric study of the effects of the shell length, angle of orientation of helical ribs of the lattice structure and their number on the disk displacement is performed. The results of calculations have been successfully verified using a finite-element analysis. The analytical formulas proposed in this work can be efficiently employed by design engineers to perform analyses of composite lattice cylindrical shells in aerospace applications.

1. Introduction

Filament-wound composite lattice cylindrical shells become structures of choice in the designs of load-carrying spacecraft tubular bodies [1,2]. Design procedures for such structures require a number of mechanical analyses to be performed to assess structural responses of these shells to various loadings. One of the analyses is related to the assessment of the deformations of the lattice tubular body of a spacecraft with the fuel tank attached at the shell midspan as shown in Fig. 1. In practice, this loading case occurs when the spacecraft is transported on the ground and its lattice cylindrical body is subjected to substantial inertia loads. The maximum effect on the shell deformation is due to transverse inertia load. The study of the bending and related transverse displacements of the lattice shell subjected to such a load is important part of the design analysis.

Two analytical models can be employed to solve the bending problem for the lattice cylinder under consideration. One approach is based on the continuum model in which the lattice structure is replaced with a continuous orthotropic shell having some effective (apparent) equivalent stiffness. Such a replacement can be done if the lattice structure is composed of the large number of helical and circumferential ribs. Example of such a model can be found in the monograph published by Vasiliev [3]. Results of the analyses of composite lattice shells using various continuum models are presented in the monographs published by Vasiliev and Morozov [4], and articles published by Totaro and Gurdal [5], Buragohain and Velmurugan [6], Paschero and Hyer [7], Totaro [8,9], and Zheng et al. [10].

Another approach that could be employed for the bending analysis is based on discrete models that are normally created using finite elements. The beam elements are used in the most popular finite-element models. Results of numerical simulations of composite lattice shells using the finite-element models are reported by Hou and Gramoll [11], Zhang et al. [12], Frulloni et al. [13], Fan et al. [14], and Morozov et al. [15].

In practice, often both aforementioned models are jointly applied to the design analysis of composite lattice structure. Using the continuum model, basic design parameters can be determined without involving any substantial computations. Further refinement of the design can be performed based on the finite-element modelling and analysis. This approach is demonstrated in the articles published by Azarov [16] and Lopatin et al. [17,18].

Application of the continuum model to the design analysis normally requires a solution of the relevant problem of structural mechanics. In this work, the continuum model is employed to perform a bending analysis of a composite lattice cylindrical shell with the rigid disk attached at the midspan. The rigid disk simulates an

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* Corresponding author.
E-mail address: e.morozov@adfa.edu.au (E.V. Morozov).

http://dx.doi.org/10.1016/j.compstruct.2016.05.015
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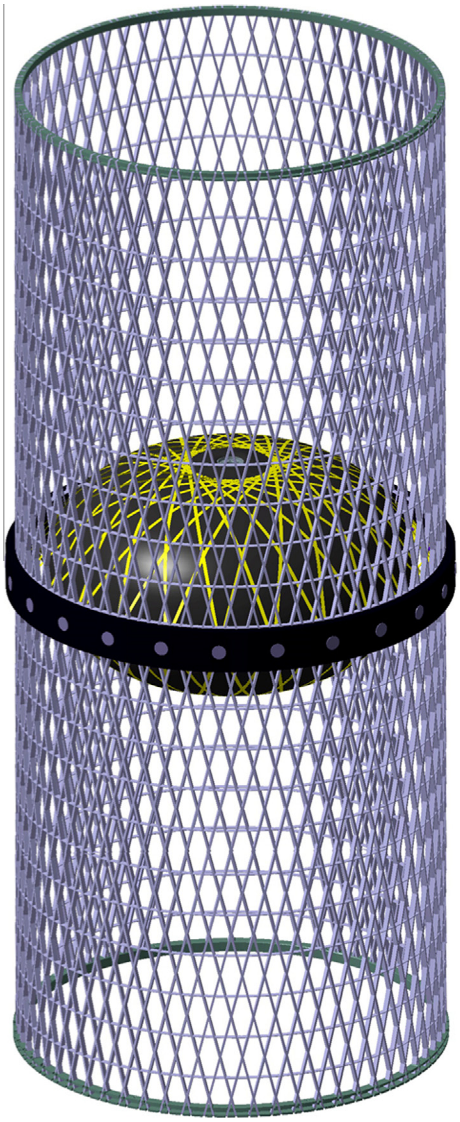

Fig. 1. Composite lattice cylindrical shell with the internal fuel tank attached at the midspan cross-section.

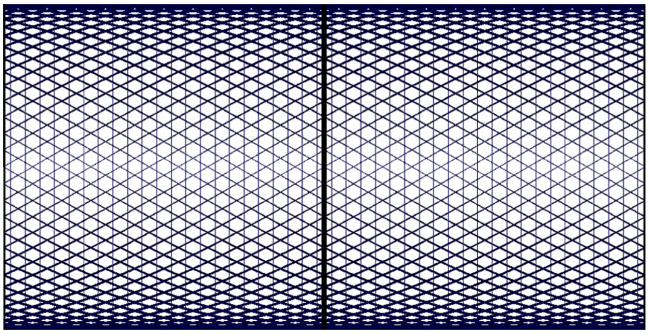

Fig. 2. Composite lattice cylindrical shell with the rigid disk attached at the midspan cross-section.

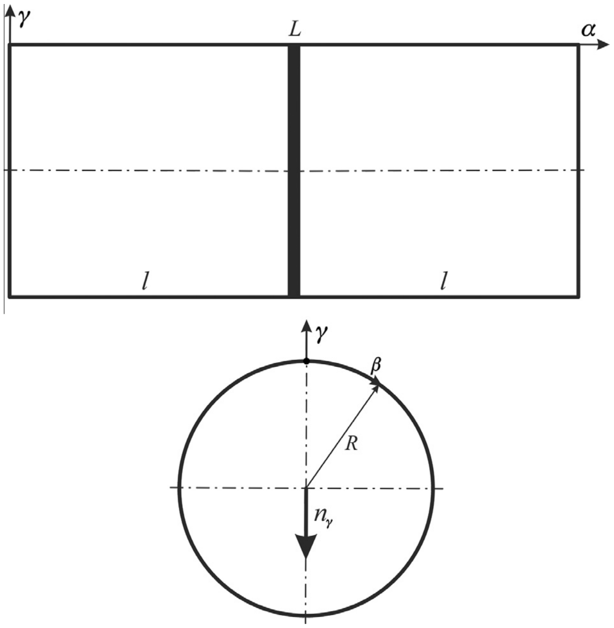

Fig. 3. Orthotropic continuous cylindrical shell with the rigid disk attached at the midspan cross-section.

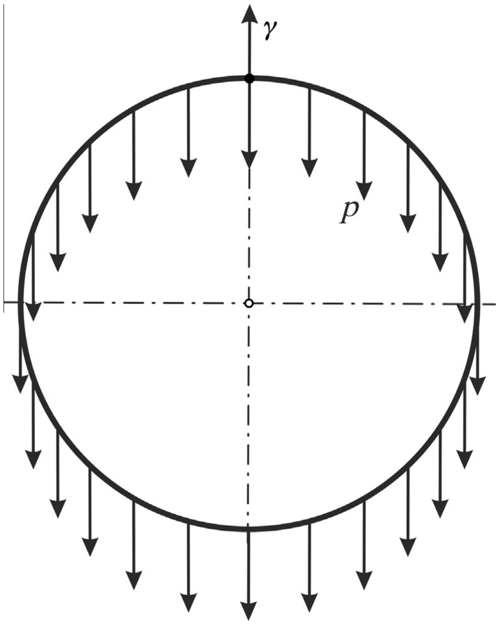

Fig. 4. Uniformly distributed inertia load *p*.

internal fuel tank attached to the shell as shown in Fig. 1. The structure is subjected to transverse inertia loads. The shell displacements caused by this loading are described by the equations of semi-membrane theory of cylindrical shells. The problem is solved for two types of the end supports. In the first case, both ends are stationary. For the second type of support, the axial displacements of the shell ends are allowed. As a result, analytical formulas for the calculation of the disk displacements are derived. Based on the values of this displacement, the bending stiffness of the structure under consideration can be assessed. This solution has been verified by comparison with the results of finite-element analysis. Using the analytical formulas, effects of the number of helical ribs, angle of their orientation, and length of the shell on the disk transverse displacement have been investigated.

2. Governing equations

Consider a lattice cylindrical shell with the rigid disk as shown in Fig. 2. In further analysis, the lattice shell is replaced with a