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Maximization of fundamental frequencies of axially compressed laminated truncated conical shells against fiber orientation

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ABSTRACT

Free vibration analyses of laminated truncated conical shells subjected to axial compressive forces are carried out by employing the Abaqus finite element program. The fundamental frequencies of these truncated conical shells with a given material system are then maximized with respect to fiber orientations by using the golden section method. Through parametric studies, the influences of the end condition, shell length, shell radius ratio and the compressive force on the maximum fundamental frequencies, the associated optimal fiber orientations and the associated vibration modes are demonstrated and discussed.

1. Introduction

Due to light weight and high strength, the use of fiber reinforced composite laminated materials in the aerospace industry has increased rapidly in recent years. The truncated conical shell configuration is widely used in aircraft, spacecraft, rocket and missile, which are frequently subjected to dynamic loads in service. Hence, knowledge of dynamic characteristics of truncated conical shells constructed of fiber-reinforced laminated materials, such as their fundamental frequencies, is essential [1].

The fundamental frequencies of laminated truncated conical shells highly depend on ply orientations, boundary conditions, and geometric variables such as shell radius ratio and shell length [1–12]. In additional, the fundamental frequencies of laminated structures are significantly influenced by the initial stresses within them [13–19]. Therefore, for laminated truncated conical shells with a given material system, geometric shape, initial stress and boundary condition, the proper selection of appropriate lamination to maximize the fundamental frequency of the shells becomes an interesting problem [20–22].

There are many computational methods available today for the vibration analysis of laminated conical shells, such as finite element method (FEM) [9], discrete singular convolution (DSC) [23,24], generalized differential quadrature (GDQ) [25] and meshless method [26]. Comparisons of the superiority and effectiveness of these methods are not the scope and the focus of this paper. Since the FEM can easily simulate the complicated and irregular geometries of structures, it is selected in this investigation to calculate the nature frequencies of the laminated truncated conical shells.

Research on the subject of structural optimization has been reported by many investigators [27]. Among various optimization schemes, the method of golden section method [28,29] is very efficient and has been successfully applied to many engineering problems. In this investigation, optimization of fiber-reinforced laminated truncated conical shells to maximize their fundamental frequencies with respect to fiber orientations is performed by using the golden section method. The fundamental frequencies of laminated truncated conical shells are calculated by using the Abaqus finite element program [30]. In the paper, the constitutive equations for fiber-composite laminate, vibration analysis and golden section method are briefly reviewed. Then the influences of the end condition, shell length, shell radius ratio and the compressive force on the maximum fundamental frequencies, the associated optimal fiber orientations and the associated vibration modes of laminated truncated conical shells are presented. Finally, important conclusions obtained from this study are given.

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2. Constitutive matrix for fiber-composite laminae

In the finite element analysis, the laminated truncated conical shells are modeled by eight-node isoparametric shell elements with six degrees of freedom per node (three displacements and three rotations). The reduced integration rule together with hourglass stiffness control is employed to formulate the element stiffness matrix [30].

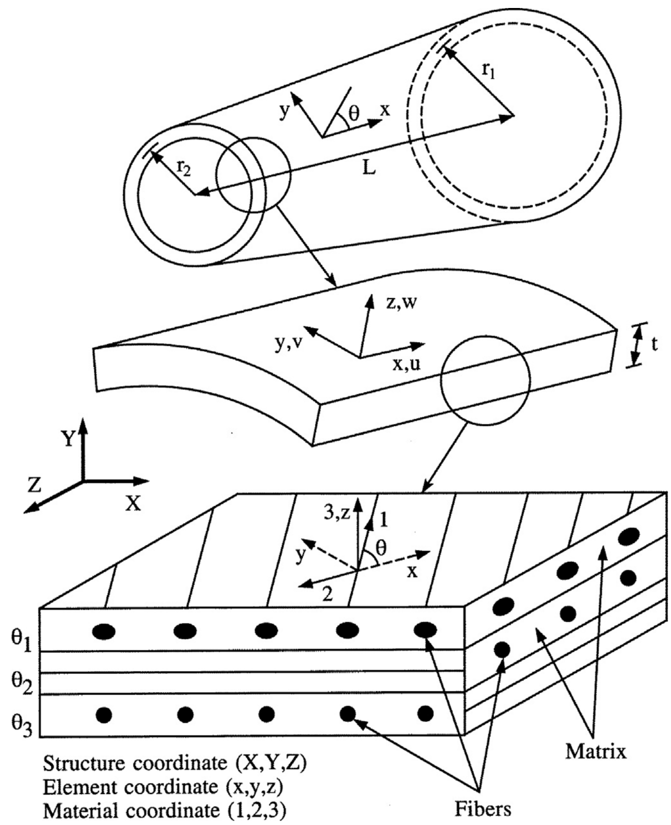

Fig. 1. Material, element and structure coordinates of laminated truncated conical shells.

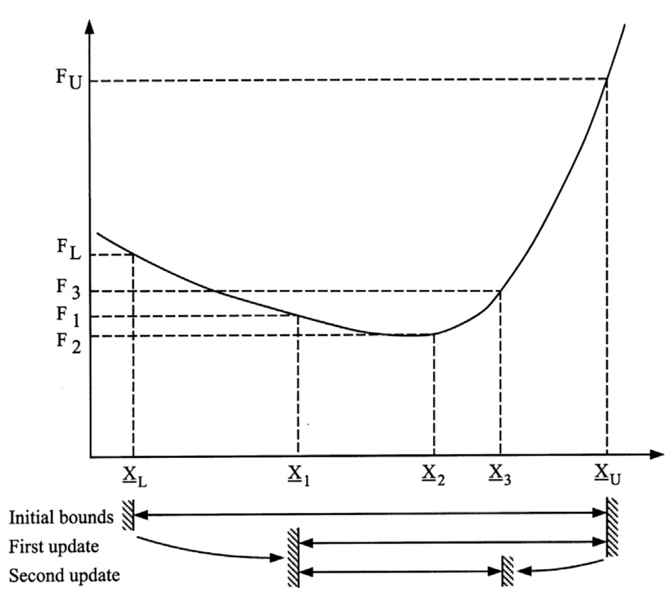

Fig. 2. The golden section method.

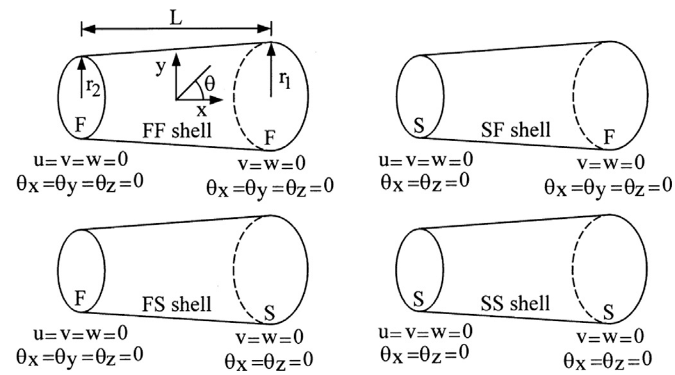

Fig. 3. Truncated conical shells with various end conditions.

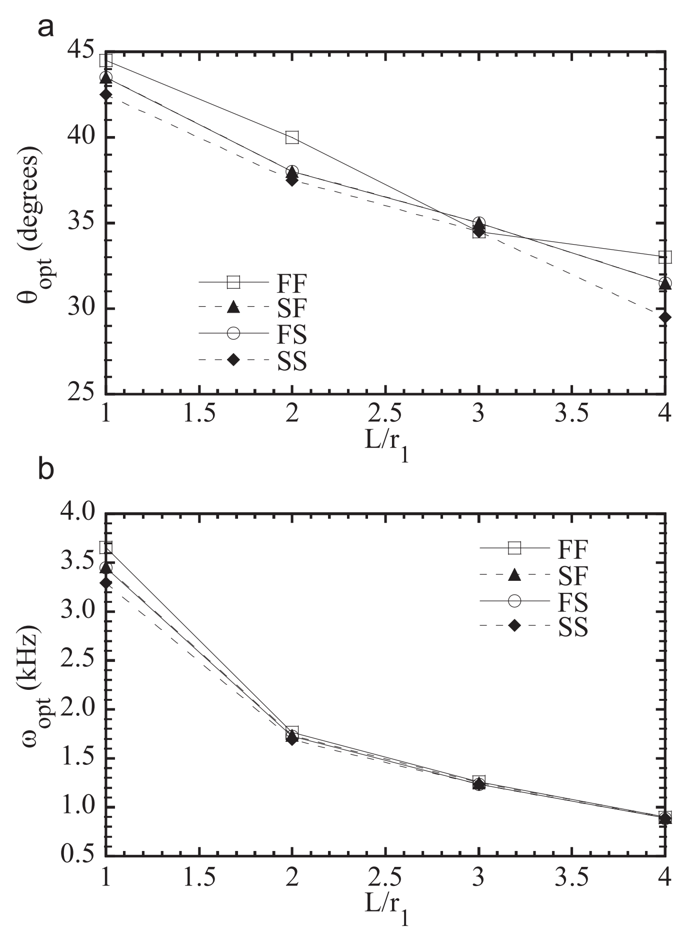

Fig. 4. Effect of end condition and L/r_1 ratio on optimal fiber angle and optimal fundamental frequency of $[\pm\theta/90_2/0]_{2s}$ laminated truncated conical shells with axial compressive force ($r_1 = 10$ cm, $r_2 = 10$ cm, $N/N_{cr} = 0.2$).