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Laminated composite stiffened saddle shells with cutouts under free vibration – a finite element approach

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A B S T R A C T

Finite element method has been applied to solve free vibration problems of laminated composite stiffened saddle shells with cutouts employing the eight-noded curved quadratic isoparametric element for shell with a three noded beam element for stiffener formulation. Specific numerical problems of earlier investigators are solved to compare their results. Moreover, free vibration problem of stiffened saddle shells with different size and position of the cutouts with respect to the shell centre for different edge constraints are examined to arrive at some conclusions useful to the designers. The results are presented in the form of figures and tables. The results are further analyzed to suggest guidelines to select optimum size and position of the cutout with respect to shell centre considering the different practical constraints.

1. INTRODUCTION

Finite element method has become an efficient tool to analyze complex structures. The dynamic analysis of shell structures, which may have complex geometry and arbitrary loading and boundary conditions, can be solved efficiently by the finite element method. Laminated composites are increasingly being used nowadays in aerospace, civil, marine and other related weight-sensitive engineering applications requiring high strength-to-weight and stiffness-to weight ratios. Among the different shell forms which are used as roofing units, saddle shells are one of them. Examples of such saddle roofs are: Warszawa Ochota railway station, Church Army Chapel, Blackheath, The Calgary, Saddledome, London Velopark. Quite often, to save weight and also to provide a facility for inspection, cutouts are provided in shell panels. In practice the margin of the cutouts must be stiffened to take account of stress concentration effects. Also, there can be some instruments directly fixed on these panels, and the safety of these instruments can be dependent on the vibration characteristics of the panels. Hence free vibration studies on saddle shell panels with cutouts are of interest to structural engineers.

Different computational models for laminated composites were proposed by Kapania [1], Noor and Burton [2], and Reddy [3]. Chao and Reddy [4] reported on the dynamic response of simply supported cylindrical and spherical shells. The transient response of spherical and cylindrical shells with various boundary conditions and loading was reported by Reddy and Chandrashekhara [5]. Chao and Tung [6] presented an investigation on the dynamic response of axisymmetric polar orthotropic hemispherical shells. Later free vibration study of doubly curved shells was done by Qatu [7], Liew and Lim [8,9], Chakravorty et al. [10-12], Shin [13] and Tan [14]. Kant et al. [15] solved problems of a clamped spherical and simply supported cylindrical cap under external pressure. Sathyamoorthy [16] reported the nonlinear vibration of moderately thick orthotropic spherical shells. Later in 1997, Gautham and Ganesan [17] reported free vibration characteristics of isotropic and laminated orthotropic spherical caps while Chia and Chia [18] reported nonlinear vibration of moderately thick anti-symmetric angle ply shallow spherical shell. Free vibration of curved panels with cutouts was reported by Sivasubramonian et. al. [19]. Qatu [20] reviewed the work done on the vibration aspects of composite shells between 2000-2009 and observed that most of the researchers dealt with closed cylindrical shells. Other shell geometries have also been investigated. Among those conical shells and shallow shells on rectangular, triangular, trapezoidal, circular, elliptical, rhombic or other planforms are receiving considerable attention. Shallow spherical shells also received

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