ABSTRACT

A generalized formulation for the analysis of doubly curved laminated composite shells has been attempted employing eight noded curved quadratic isoparametric finite element with all three radii of curvature and considering the effect of shear deformation. The formulation has been made such that it can also be applied to the isotropic shells as a special case. Each of the eight nodes of the element has five degrees of freedom and each of the displacement parameters is approximated with quadratic polynomials having eight terms. Element stiffness matrices have been formed from the Principle of Minimum Potential Energy and the inclusion of six rigid body modes has been tested by the eigenvalue analysis of the element stiffness matrix.

The present formulation has been applied to eleven specific shell problems consisting of (a) the paraboloid of revolution, (b) the conoidal and (c) the hyperbolic paraboloid shells made up of isotropic material, symmetric and anti-symmetric cross-ply laminates and anti-symmetric angle-ply laminates. The results of seven problems have been compared with those of earlier investigators in order to authenticate the present formulation. Furthermore, four problems have been utilized to study the behaviour of different shell characteristics for various lamination configurations as well as shell forms in order to identify the suitability of a- particular type of material or shell form over others. The major findings of the present investigation are briefly stated below :

The test of convergence shows that the use of 2x2 Gauss quadrature points yields a better convergence of results than the use of 3x3 or 4x4 Gauss quadrature points. In general, the

laminated composite shells require finer mesh sizes than the isotropic shells, for good convergence, possibly due to the material anisotropy in the thickness direction.

The comparative study between the shell characteristics obtained by using the author's formulation and those of earlier investigators yields a close agreement. In some cases, the present results are observed to be more satisfactory than those obtained earlier. The eigenvalue analyses performed on the element stiffness matrices for thirty-six cases of four laminated composite shell problems have yielded six nearly zero eigenvalues corresponding to six rigid body modes.

The results of the simply supported composite paraboloid of revolution shell problem reveal that zero and 90 degree laminates should be avoided as they undergo excessive deflection. The performance of other symmetric laminates is superior to the anti-symmetric laminates. In general, the values of shell characteristics decrease with the increase in number of layers.

The performance of the 90 degree laminate is found to be poor in comparison to that of other cross-ply laminates of the simply supported conoidal shell. The performance of the symmetric laminates is, in general, better than that of the anti-symmetric laminates.

The comparative performance matrix proposed by the author is very useful in assessing the relative performance of two laminates for each of the shell actions in order to exploit the full potentiality of these laminated composite materials for the purpose of design.

For the simply supported composite hyperbolic paraboloid shell, the number of layers does not have any significant role as in the case of other doubly curved shells. The use of zero and 90 degree laminates ~~are~~ is not recommended for this type of shell as they undergo excessive deflection and exhibit drastic changes in other shell actions. The symmetric laminates appear to be superior to the anti-symmetric ones on the basis of careful examinations of the contour plots of moments.

The study of behaviour of three types of anti-symmetric angle-ply laminates for a simply supported paraboloid of revolution shell reveals that the values of different shell actions decrease with the increase in number of layers for each of the three types of laminates. The maximum values of deflection are lower for 45/-45 laminates than those of 30/-30 and 60/-60 laminates. This is largely due to the fact that all the 30/-30 and 60/-60 laminates possess only the downward deflection throughout the shell, whereas 45/-45 laminates possess both downward and upward deflection.

Under similar geometric dimensions, loadings and boundary conditions, the anti-symmetric angle-ply laminates establish their superiority to the cross-ply laminates. The hyperbolic paraboloid shell of cross-ply laminates, however, appears to be more efficient than the paraboloid of revolution shell of either cross-ply or anti-symmetric angle-ply laminates.

Key words : Shell, Doubly curved, Laminated composite, Finite element, Isoparametric, Paraboloid of revolution, Conoidal, Hyperbolic paraboloid, Cross-ply, Angle-ply, Symmetric, Anti-symmetric, Deflection, Shell action.