Buckling of Laminated Plates with Cutout using Higher Order Theory

Alfia Bano*, **P. M. Mohite**† and **Ashwini Kumar***

* Department of Civil Engineering, Indian Institute of Technology,
Kanpur, Uttar Pradesh, 208016, India
† Department of Aerospace Engineering, Indian Institute of Technology,
Kanpur, Uttar Pradesh, 208016, India
Email: alfia@iitk.ac.in

Abstract

A generalized finite element based formulation using higher order shear deformation theory is developed for buckling analysis of laminates with cutout under varying in-plane loads, combined with shear. The advantage of this model is that sequence of higher models can be obtained. In this study Green's Lagrange strains are used to derive the geometric stiffness matrix to incorporate the effect of in-plane displacements in-addition to out of displacement in geometric nonlinearity. For the purpose of analysis laminates with circular cutouts are considered to examine the effect of ply orientation, stacking sequence and boundary condition.

1. Introduction

In many practical situations cutouts are provided in laminated plates for various mechanical and electrical systems. These cutouts influence the stress distribution pattern and ultimately the buckling behavior of the structure considerably. Nemeth [1], studied the buckling behavior of rectangular symmetrical angle-ply laminates with a circular cutout. An approximate analysis for buckling load of bi-axial, shear and combined shear and compression-loaded anisotropic panels with centrally located elliptical cutouts was carried out by Britt [2]. The results presented in literature indicate that the buckling behavior of laminates depends on interaction among stacking sequence, cutout shape, and edge restraints and are needed to investigate in more detail.

2. Theoretical model

The finite element formulation is based on higher order shear deformation theory. In this the displacement fields are approximated using higher order polynomial of thickness coordinate as given in equation below.

$$u(x,y,z) = \sum_{i=o}^{n1} u_i(x,y)\, f_i(z)$$

$$v(x,y,z) = \sum_{i=o}^{n2} v_i(x,y)\, f_i(z)$$

$$w(x,y,z) = \sum_{i=o}^{n3} w_i(x,y)\, f_i(z)$$

The unique feature of this formulation is that it is not restricted to particular type of plate theory or dimensionally reduced model but rather can be used in conjunction with the available plate theories for both thin and thick plates and even for fully three-dimensional models. One more advantage of this formulation is that we can have higher-order variation of transverse normal strains which is generally ignored.

The buckling formulation proposed by Actis et al [3] is used for the analysis. Here the problem is formulated in two steps, first solving the linear elasticity problem for the reference load and constraints to obtain the accurate stress distribution within the plate. Subsequently, using these stresses, the geometric stiffness matrix and then minimum buckling load factor is evaluated.

3. Sample Result

The buckling behavior of [θ/-θ] square laminated plate (b/h = 10) in the presence of centrally located circular cutout with r/b= 0.1 is studied. Different type of boundary condition such as SSSS and SFSF is used for analysis with S as simple supported and F as free edge. Figure 1 shows the effect of ply orientation and edge conditions on critical load parameter. It is observed that for SSSS boundary conditions, the mean buckling load of the plate with θ lying between 45º to 90º, is found to be higher compared to plates without cutout. However, for SFSF the load decreases monotonically with increasing ply orientation, and are lower compared to plates without cutout.

The final paper would contain the detailed description of the model developed. Effects of higher order models on the buckling behavior of different laminates under the combination of in-plane and shear loading will be addressed in detail for different cutout ratio and shape, ply orientation, and boundary conditions.

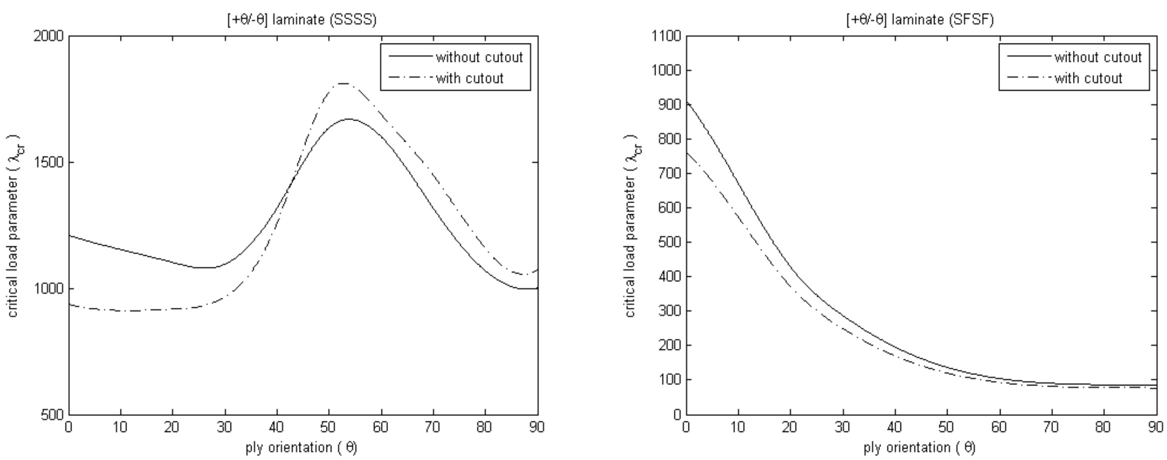

Fig. 1 Effect of ply orientation and boundary condition on mean buckling load for [θ/-θ] square laminated plate under uniaxial compression

4. Summary

The buckling behavior of laminates is strongly influenced by applied boundary conditions, ply orientation, and plate aspect ratio. Perforated plates under compressive load with some specific boundary conditions and layup sequences show higher buckling load as compared to plates without cutout.

5. References

[1] Nemeth, M.P., 1988, Buckling behavior of compression-loaded symmetrically laminated angle-ply plates with holes, AIAA Journal, 26(3), 330-336.

[2] Britt, V.O., 1994, Shear and compression buckling analysis for anisotropic panels with elliptical cutouts, AIAA Journal, 32(11), 2293-2299.

[3] Actis, R.L., Szabo, B.A. and Schwab,C., 1999, Hierarchic models for laminated plates and shells, Comput. Methods Appl. Mech. Engg., 172, 79-107.