International Journal of Engineering Research and Technology.
ISSN 0974-3154 Volume 6, Number 3 (2013), pp. 379-386

http://www.irphouse.com

An Analysis to Mitigate Induced Stresses in Orthotropic Plates with Central Square Cut-out

Kanak Kalita[1], Abhik Kumar Banerjee[2] and Salil Haldar[3]

[1,2]PG Scholars, Department of Aerospace Engineering & Applied Mechanics
[3]Department of Aerospace Engineering & Applied Mechanics
Bengal Engineering and Science University,
Shibpur Howrah, West Bengal, India.

Abstract

Orthotropic plates have found a wide variety of application in today's scenario in different areas viz; construction, automobile, aerospace and mechanical. But the design requirement involves incorporation of cutouts of various geometry like circular and square, which results in stress concentration in thereby reducing the mechanical strength of the structure. Hence it is necessary to find ways to mitigate this stress. In this paper the problem of reduction of principal stresses by placing symmetric auxiliary holes around the central square cutout in an orthotropic plate is studied. Small auxiliary holes are preferred for the study since it would involve removal of minimal area from the orthotropic plate. Effect of the distance of the auxiliary holes from the central cutout on stress mitigation is studied. Since analytical treatment of this kind of problem is difficult, a popular finite element package ANSYS is used for the analysis. Results for orthotropic plates with all edges fixed is presented here in graphical form.

Keywords: ANSYS, auxiliary holes, cut-out, finite element method, orthotropic plate.

1. Introduction

With advances in science and technology orthotropic and composite materials are becoming increasingly popular. Plywood can be considered to be orthotropic under certain conditions. Paper and paper laminates are also orthotropic. Resin laminates made of sheets of woven glass fiber, used in aircrafts, are also orthotropic, as are most of the core materials used in sandwich panels in the construction of high-speed aircraft.

Cutouts are structural requirements of many aeronautical, mechanical and civil structures. In aircrafts components (such as wing spars and ribs) cutouts are provided to reduce the weight and to lay fuel lines and electrical lines. These are also provided for access to and service of interior parts in aircrafts and in bridges having plated structures such as box girders. These cutouts make the structure weak and susceptible to failure. Therefore, it is necessary to investigate the state of stress around the holes for the safety and proper design of such structure and find ways to mitigate the induced stresses.

Motok [1] carried out stress concentration studies on the contour of a plate opening of an arbitrary corner radius of curvature. Meguid [2] presented a technique for reduction of SCF in a uni-axially loaded plate with two coaxial holes by introducing defense hole system- material removal in the form of circular holes. Defense hole system is a technique of material removal for stress mitigation using finite element method. Mittal and Jain [3] proposed optimization of design of square simply supported isotropic plate with central circular hole subjected to transverse static loading by Finite Element Method. They have reported around 30% reduction in SCF. They proposed four auxiliary holes around circular hole in square plate. A further modification of work was carried out by optimization of auxiliary hole shape by giving elliptical shape to the auxiliary holes. Optimal hole shape for minimum stress concentration in two dimensional finite plates is given by Zhixue Wu [4]. According to Heywood [5], stress concentration can be reduced by introducing smaller auxiliary holes on either side of the original hole, which smoothen the flow of the tensile principal stress trajectories past the original hole. Sanyal and Yadav [6] have extended the work of Heywood and others by proposing the optimum distance and size of auxiliary holes for mitigation of SCF. By introducing the auxiliary holes in the line of original hole, about 17% mitigation in SCF is achieved. They have proposed an optimum distance between the original hole and relief hole and also an optimum size of relief hole by assuming elliptical stress flow lines.

2. Problem Description and Element Selection

A thin rectangular orthotropic plate of 1500mm x 1000mm (A x B) is considered for study. A Square cutout of 200x200mm are provided at the center. The material properties of the orthotropic material (e-glass/epoxy) [7] are Ex, Ey, Ez, Gxy, Gyz, Gzx, μxy, μyz, μzx 39 GPa, 8.6 GPa, 8.6 GPa, 3.8 GPa, 3.8 GPa, 3.8 GPa, 0.28, 0.28, 0.28 respectively. Transverse load in form of uniformly distributed load of 1N is applied for all cases. All edges of the plate are fixed.

An 8 noded shell element, (specified as SHELL 281 in ANSYS) is used throughout the study. The element has eight nodes with six degrees of freedom at each node: translations in the x, y, and z axes, and rotations about the x, y, and z-axes (when using the membrane option, the element has translational degrees of freedom only). Thus each element has 48 degree of freedom in total. SHELL281 is well-suited for linear, large rotation, and large strain nonlinear applications. A mesh discretization of 30 x 30 was used throughout the analysis.

3. Methodology

Fig.1 illustrates the various dimensions considered for auxiliary hole placement. All variation of distances of auxiliary holes from the periphery of the central cutout which are X_1, Y_1 and radius of the auxiliary holes R_1 are taken as functions of side of the central cutout (b). Three different auxiliary hole sizes of 10mm, 20mm and 40mm are taken. Distance of the auxiliary holes is varied as distance/cutout side length ratio. Three different methods of auxiliary hole placement are considered. One of our main concerns while placing the auxiliary holes is to keep their sizes minimum.

Method 1: Two auxiliary holes with radius R1 are placed on either side of the main hole on y center line with variation in X_1.

Method 2: Four auxiliary holes are placed, two same as *method 1* and other two with radius R_1 at x center line at Y_1 such that $X_1=Y_1$. Thus four symmetrical holes are placed all around the main hole.

Method 3: Method 3 is same as method 2 but $X_1 \neq Y_1$.

The results so obtained are presented below in tabulated form and few plots are drawn for significant results.

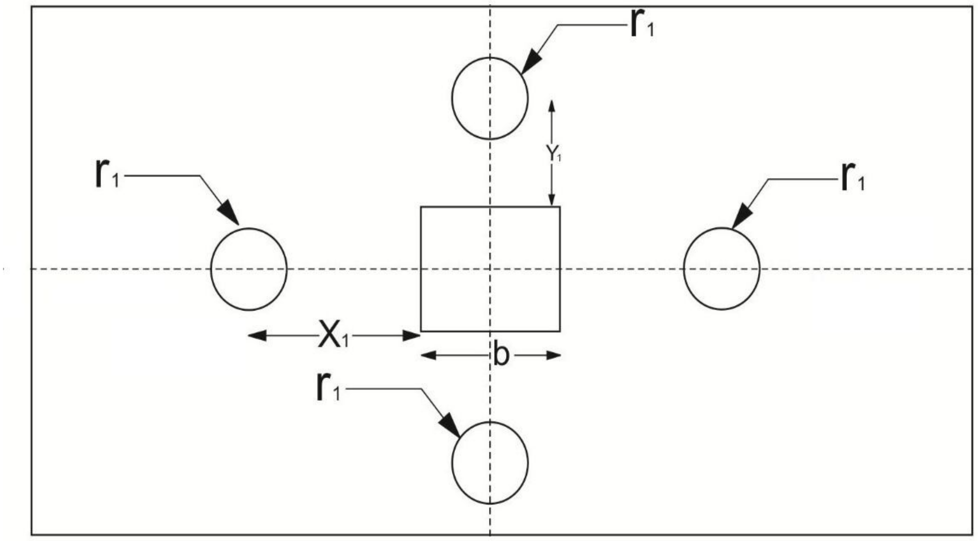

Figure 1: Basic dimensions used for placing the auxiliary holes.

4. Results and Discussion:

4.1 Optimizing distance X_1

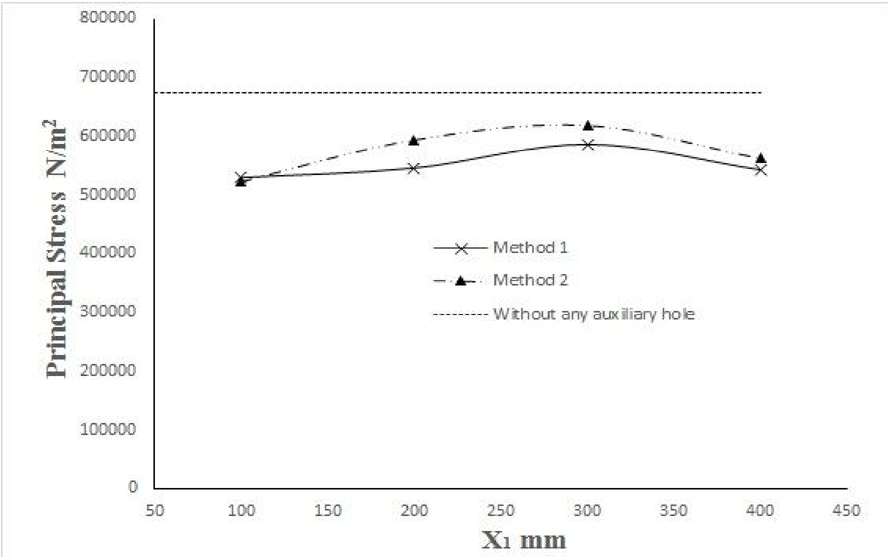

Figure 2: Principal stress vs. X_1 for method 1 and method 2 by using auxiliary holes of radius $R_1 = 20$ mm.

Though we considered three values for R_1 in our study, Fig. 2 shows the variation of principal stress with change in distance X_1 for a radius $R_1 = 20$ mm only for clarity of plots. Also plots of other radius follow more or less similar pattern although using $R_1 = 20$ mm showed better reduction in stresses. The dotted line shows the principal stress for orthotropic plate without using any stress reduction technique. When the auxiliary holes are placed very near the central hole the principal stresses in the orthotropic plate elevate (not shown in graph). At a distance of 0.5 times of the side of the cutout (i.e. 100 mm) stresses decrease by about 21.26 % for method 1 and by about 22.45 % using method 2 compared to the plate without any auxiliary holes. When the distance X_1 is increased to 1.5 times the side of the cutout (i.e. 300 mm) stress increase a little but are well below the stress of the orthotropic plate without any auxiliary hole. At $X_1 = 300$ mm reduction in stresses is about 13 % for method 1 and about 8.1 % using method 2.

4.2 Optimizing radius R_1

Fig. 3 shows the effect of radius R_1 on principal stress for method 1 and 2. For the plots in fig. 3 X_1 was taken as 100 mm for method 1 and X_1=Y_1=100 mm for method 2. The radius R1 was then varied for both method 1 and 2 as R_1= 10 mm, 20 mm, 40 mm. The distance X_1 was taken as 100 mm because fig. 2 clearly depicts stress reduction by using X_1=100 mm is maximum for both method 1 and 2. For $R_1 = 10$ mm reduction of stress is 18.72 % for method 1 and 15.31% for method 2. As R_1 is increased the further reduces to 21.26 % for method 1 and 22. 45 % for method 2. Further increase in auxiliary hole radius, R_1= 40 mm reduction of stresses is less which is about 14 % for method 1 and 20 % for method 2.

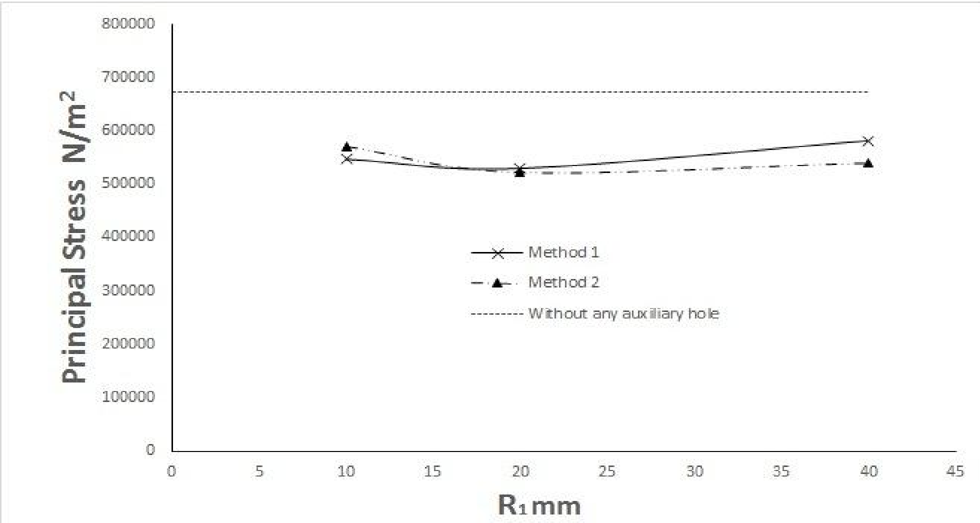

Figure 3: Principal stress vs. R_1 for method 1 and method 2 by using auxiliary holes at X_1 = 100 mm.

4.3 Optimizing distance Y_1

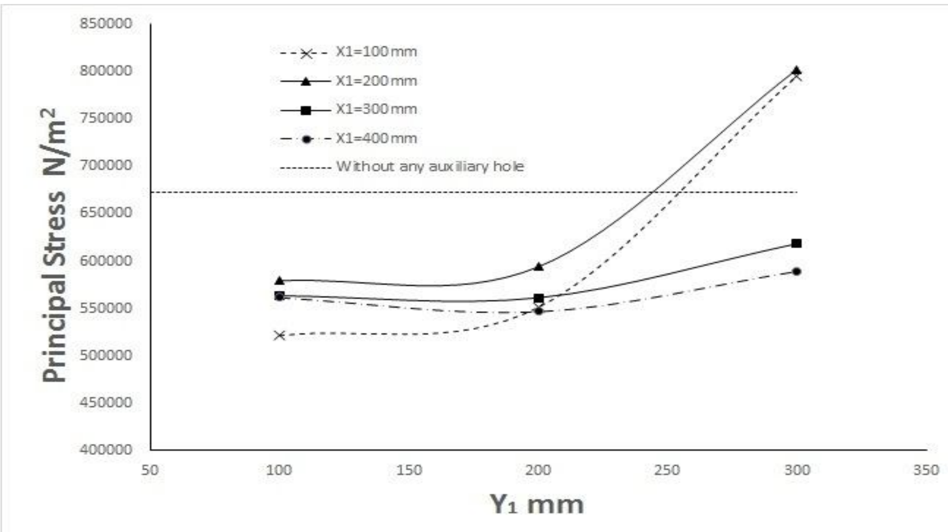

Figure 4: Principal stress vs. Y_1 for method 3 by using auxiliary holes at R_1 = 20 mm.

Fig. 4 shows the effect of distance Y_1 on principal stress for method 3 with auxiliary holes of radius 20 mm. The plots clearly depicts the effect of Y1 but at same time it is interesting to note the changes that plot undergoes as we vary X1. Even a crude peek on the plots reveals that plots follow a similar pattern such at that at Y1 near the central cutout reduction is maximum and with increase in Y1 reduction in stresses become less. For X1 = 100 mm and 200 mm sufficient reduction of stress is seen at Y_1=100 mm but as Y1 is increased the stresses increase and at Y1= 300 mm the stresses elevate beyond the stress without any auxiliary hole. Plots For X_1 = 300 mm and 400 mm look alike with maximum reduction at Y1 = 200mm.

5. Conclusion

Any abrupt change in dimensions gives rise to high stresses around the discontinuity and change in stress flow lines is seen. Through gradual change in the structure reduction in these accumulated stresses is seen. In case of plates with central cutouts this can be achieved by drilling auxiliary holes around the main hole periphery. In general *method 1* and *method 2* seems to work better at cutout proximity of about 0.5 times the main cutout dimension. X1 should be about 0.5 times the cutout width. An auxiliary hole of area about 0.03 times of the central cutout produces excellent result. Y1 should be equal to X1 for obtaining good results. Also it is seen that stress reduction of the orthotropic plate hole depends not only on proximity of auxiliary hole to the central cutout but also whether the auxiliary hole is placed at vicinity of the edge of the plate. Hence it can be concluded that the use of auxiliary hole is practically more suitable for plate with infinite dimension. Due to sufficient availability of space stress would be lowered by significant amount. In our best case for method 1 all the auxiliary holes combined together occupied an area of 6.28 % of that of the cutout and only 0.17 % of the plate area for a reduction of stress of more than 21.26%. For method 2 the reduction in stresses is 22.45% for removal of only 0.34 % of solid plate area.

6. Acknowledgements

The authors are highly grateful to the department and the university for providing all kinds of support to carry out the work successfully.

References

[1] M. D Motok (1997).” Stress Concentration on the Contour of a Plate Opening of an Arbitrary Corner Radius of Curvature”, Marin Structures, Vol. 10, No. 1, pp. 1-12.

[2] S. A. Meguid, (1986) “Finite element analysis of defence hole systems for the reduction of stress Concentration in a uniaxially–loaded plate with coaxial holes,” Engineering Fracture Mechanics, vol. 25, no. 4, pp. 403-413.

[3] N. D. Mittal and N. K. Jain, (2007) "The optimize design of a square simply supported isotropic plate with central circular hole for reduction of stress concentration subjected to transverse static loading," Proceedings of ICTACEM.

[4] Z. Wu, (Feb, 2009) "Optimal hole shape for minimum stress concentration using parameterized geometry models," Structural and Multidisciplinary Optimization, vol. 37, no. 6, pp. 625-634.

[5] R. B. Heywood, (1952) Designing by Photo Elasticity. London: Chapman & Hall Ltd.

[6] S. Sanyal and P. Yadav, (5-8 July 2006) "Multiple relief holes for stress mitigation in infinite thin plate with single circular hole under axial loading," 2nd International Conference SCCE.

[7] N.E Shanmugam,(1997) "Openings in Thin-Walled Steel Structures", Thin-Walled Structures, Vol. 28, No. 3-4, pp. 355-372,

[8] A.I. Zirka, M. P. Malezhik, and I. S. Chernyshenko, (2004) "Stress distribution in an orthotropic plate with circular holes under impulsive loading," International applied mechanics, vol. 40, and no. 2.

[9] A.Tafreshi, (1995) "Numerical analysis of stresses at oblique holes in plates subjected to tension and bending", Journal of strain analysis, vol. 30 no4, PP 317-323.

[10] M. Suneelkumar, p. Alagusundaramoorthy and R. Sundaravadivelu, (June 2007) "ultimate strength of square plate with rectangular opening under axial compression" Journal of naval architecture and marine engineering,.

[11] T. Hasan, A. Das, T. Rahman, S. C. Chowdhury, and M. T. Alam, (2009)"Stress analysis of steel plate having holes of various shapes, sizes and orientations using finite element method," Proceedings of the International Conference on Mechanical Engineering 2009 (ICME2009) Dhaka, Bangladesh, December.

[12] S. A. Meguid, (1986) "Finite element analysis of defence hole systems for the reduction of stress Concentration in a uniaxially– loaded plate with coaxial holes," Engineering Fracture Mechanics, vol. 25, no. 4, pp. 403-413.

[13] S. Timoshenko and J. N. Goodier, (1988) Theory of Elasticity. New York: McGraw Hill Book Co.