International Journal of Scientific & Engineering Research, Volume 7, Issue 12, December-2016
ISSN 2229-5518

Stress Concentration Factor Converts into Stress Intensity Factor using ANSYS

Ankur Joshi[1]
[1]*Assistant Professor, Mechanical Department,*
Vadodara Institute of engineering Kotambi, Vadodara

[1]ankur.joshi1990 @gmail.com

ABSTRACT
Analysis has been done by using ANSYS APDL software package for different values of aspect ratio in a plate with central-elliptical hole and is subjected to a pressure at the ends. A static load is gradually applied to a mechanical component. It's been observed that the presence of holes in the body makes it prone to stress concentration and thus the stress near these stress raisers becomes larger than the nominal stress by a certain amount. This stress can be determined by analytical methods or by Finite Element Analysis. FEA divides (discretize) the structure into small but finite, well defined, elastic substructures (elements). A continuous elastic plate of size (400x100x10) mm^3 is prepared and material for which is selected as steel with a central elliptical hole of major radius of 10mm. The minor radius has been determined in each case with the help of the aspect ratio for each case. The plate is discretized with SOLID 8 QUAD 183 elements which are already available in the element library of ANSYS. The model has analyzed for different aspect ratios viz; 0.1, 0.2, 0.3,…..,0.9 and 1.0 of the elliptical hole by keeping the dimensions of plate fixed and value of maximum equivalent Von-Mises stress and deflection of plate under a constant pressure is determined with the help of ANSYS. Effect of the geometry of hole on the stress distribution around the hole is studied. The results of various analyses is presented with the help of tables, graphs and nodal plots as provided by ANSYS.

Key words: Stress concentration factor, stress intensity factor, aspect ratio, von-mises stress

I. INTRODUCTION

Design may be to formulate a plan for the satisfaction of a specific need or to solve a problem. If the plan results in the creation of something having a physical reality, then the product must be functional, safe, reliable, competitive, usable able to manufacture and marketable. With the global advent of CAD, the development of 3-Dimensional designs with which conventional dimensional orthographic views with automatic dimensioning can be produced. Mathematical analysis and experimental measurement show that in a loaded structural member, near changes in the section, distributions of stress occur in which the peak stress reaches much larger magnitudes than does the average stress over the section. This increase in peak stress near holes, grooves, notches, sharp corners, cracks, and other changes in section is called stress concentration. The section variation that causes the stress concentration is referred to as the stress raisers.

An isotropic, elastic rectangular plate with central elliptical hole under longitudinal static loading, is extensively used in several industrial fields such as marine, aerospace and automobile, etc. Precise knowledge of deflection, stresses and stress concentration are required in design of plates with hole. Stress concentration rises due to sudden change in geometry of plate under loading. So, stress distribution is not uniform throughout the cross section. Failures due to fatigue cracking and plastic deformation commonly happens at points of stress concentration.

Machine components have regions in which the stress is significantly greater than theoretical calculations is due to abrupt changes in geometry or stress raisers such as notches, holes, and fillets. Some internal irregularities (non-homogeneities) of the material also created by certain manufacturing processes like casting and molding. Several machining operations created surface irregularities such as cracks and marks. These Stresses are highly localized effects which are functions of geometry and loading and known as stress concentration. Stress concentration can be consider as stress concentration factor and stress intensity factor during designing of machine components. The Stress Intensity Factor is basically used in fracture mechanics to predict the stress state (stress intensity) near the tip of a crack caused by a remote load or residual stresses.

In this work, the standard method to calculate the stress concentrations factor (K_t) and stress intensity factor (K_I) caused by geometric features are compared with commercially available software ANSYS. This model can also be applied to materials that exhibit a small scale yielding at a crack tip.

Paul and Rao [1-2] represented a theory for evaluation of SCF (K_t) for thick plate of laminated FRP with the help of Lo-Christensen-Wu higher order bending theory under transverse loading. Effect of fiber orientation for a unidirectional composite laminate with FEM by assuming a plane stress problem under plane static loading was analyzed by Shastry and Raj [3]. Iwaki [4] worked on concept of stress concentration in a plate with two unequal circular holes in 1980 and finding out effect of unequal holes on stress concentration factor. After few years in 1995 Xiwu et al. [5] evaluated stress concentration of finite composite laminates with elliptical hole and multiple elliptical holes based on classical laminated plate theory. Ukadgaonker and Rao [6] proposed a general form of mapping function and an arbitrary biaxial loading condition for stresses around holes in symmetric laminates. Ting et al. [7] introduced new a theory for stress analysis by using rhombic array of alternating method for multiple circular holes. Chaudhuri [8] worked on stress concentration around a part through whole weakening a laminated plate by finite element method. Peterson [9] has developed graphical representation of stress concentration factor in isotropic plates. He is also included mathematical analysis for different types of abrupt changes in plates. Patle et al [10] determined stress concentration factors in plate with oblique hole using FEM. Various angle of holes have been considered to evaluate stress concentration factors at such holes. The stress concentration factors are based on gross area of the plate.

II. MATERIALS AND METHODS

In the present study, the effect of aspect ratio (b/a) of a central elliptical hole on the stress distribution and deflection in a rectangular 3D plate of dimensions 400mm x 100mm x 10mm under longitudinal static load of magnitude 10Mpa has been analyzed using finite element method. Due to the presence of elliptical hole in the plate the maximum equivalent Von-Mises stress induced is expected at the corner of major axis of the hole. Stress concentration is defined as localization of high stresses due to the irregularities present in the component and abrupt changes of the cross-section. In the present analysis, ANSYS has been employed to find out the localized stresses in the plate. The amount of stress concentration due to irregularities in any body is measured by the stress concentration factor (SCF) which is denoted by K_t and given by the generalized relation:

$$\mathrm{Kt} = \frac{higher\ value\ of\ actual\ stress\ near\ discontinuity}{nominal\ stress}$$

- Gross area (area of the plate ignoring the hole) has been considered in this analysis.

The gross area approach is helpful for the design engineer in the way that it gives the SCF due to discontinuity depending up on the applied load. Although the actual SCF is calculated with the help of net cross-sectional area of the plate. The stress concentration factor for an elliptical hole in a rectangular plate is given as:

$$Kt = 1 + 2(\frac{a}{b})$$

Where,
a = Length of major axis and
b = Length of minor axis.
According to eq. 1, as the value of b decreases, the value of Stress concentration factor increases and it tends to infinity as b approaches zero.

The 3D model of the elastic rectangular plate has been created and discretized using modelling and meshing capabilities of ANSYS. The elements used for discretization are SOLID8 QUAD 183.It can tolerate irregular shapes without as much loss of accuracy.

SOLID95 elements are well suited to model curved boundaries. The element may have any spatial orientation. It has plasticity, creep, stress stiffening, large deflection, and large strain capabilities. The model geometry and various boundary conditions applied are shown in the Fig. 1.

The Young's modulus (E) and Poisson's Ratio (ν) of the steel plate are taken to be equal to 2.1x10! N/mm^2 and 0.3 respectively.

III. RESULTS AND DISCUSSION

The Maximum Von-Mises stress and displacement for different values of b/a (aspect ratio) of the central elliptical hole in the elastic plate are determined with the help of ANSYS. The results are displayed with the help of graphs, tables and figures:

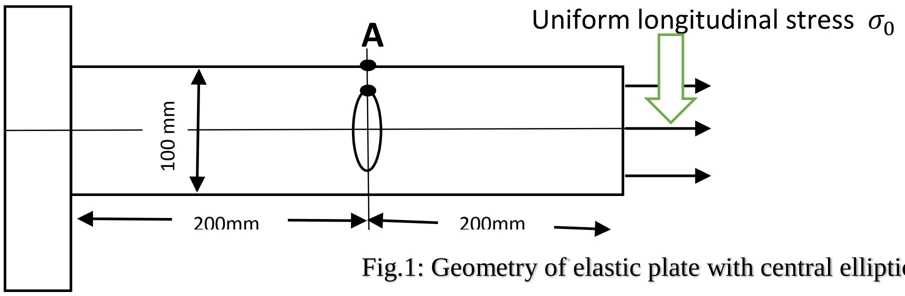

Fig.1: Geometry of elastic plate with central elliptical

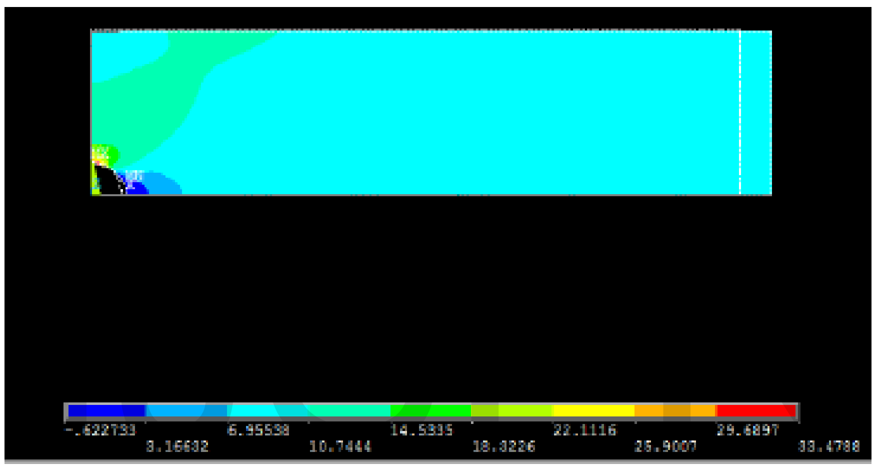

Fig.2: Von-mises stress for aspect ratio 0.9

Analysis Type	Static structural
Element Type	Solid 8 Quad 183
Element Size	1.5
Element Behavior	Plane Stress With Thickness

Table-1 Effect of aspect ratio of elliptical hole on Von Mises stress for b/a = 0.9

Hence the Stress Concentration Factor is:

$$\alpha_0 = \frac{\sigma_{max}}{\sigma_0}$$

Also the theoretical Stress Concentration Factor obtained using the following equation is: 3.11

Percentage error in theoretical and practical values:

$$\frac{3.34 - 3.11}{3.34}$$

= 0.068%

Similarly, we can find out the Stress Concentration Factor for different aspect ratios as below:

Aspect Ratio (b/a)	Theoretical (Kt)	Practical (Kt)	% error
0.9	3.11	3.34	0.068
0.8	3.50	3.60	0.027
0.7	3.84	3.95	0.027
0.6	4.32	4.384	0.013
0.5	5	4.94	0.012
0.4	6	5.71	0.048

Table -2 Stress Concentration Factor for Different Aspect Ratios

The Von-Mises stress for aspect ratio 0.3 is: 65.63 MPa.
Hence the Stress Concentration Factor is: 6.56.
The theoretical Stress Concentration Factor obtained is: 7.66 and the percentage error between theoretical and practical values is 0.14%.
Here at lower values of aspect ratio, the difference between theoretical and practical values is more. Hence error increases at lower values of aspect ratio. Hence, therefore, we have to find the Stress Intensity Factor for lower values of aspect ratio (b/a<0.4) as Stress Intensity Factor deals is used in fracture mechanics to predict the stress state (stress intensity) near the tip of a crack caused by a remote load or residual stresses and as aspect ratio is reduced a crack will form instead of an elliptical hole.

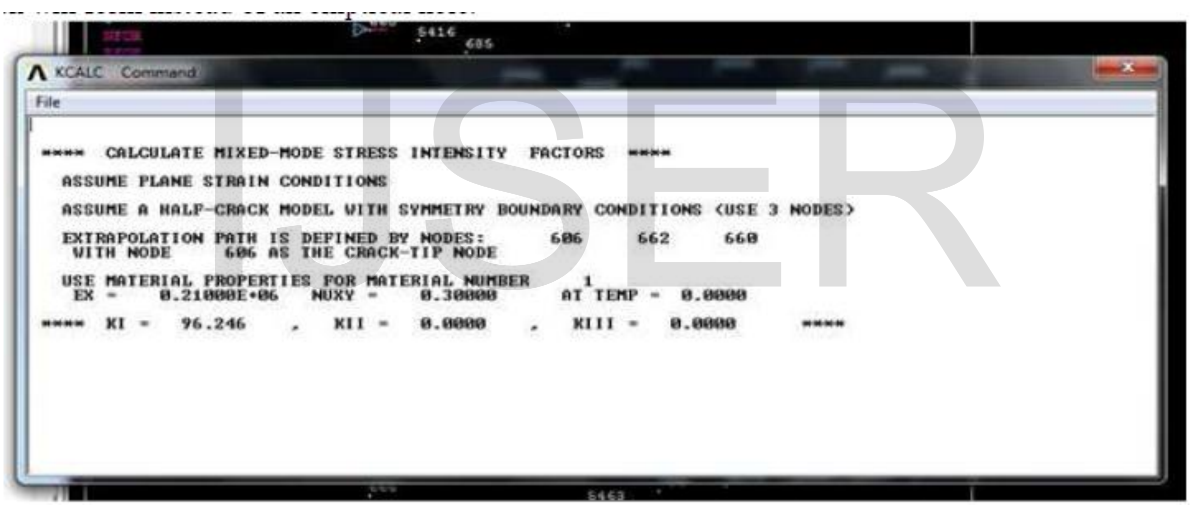

Fig. 3 Stress Intensity factor for aspect ratio 0.3

Analysis Type	Static structural
Element Type	Solid 8 Quad 183
Element Size	1.5
Element Behavior	Plane Strain
Work Plane	Local coordinate system prepared by 3 nodes

Table -3, For Aspect Ratio 0.3

The Stress Intensity Factor obtained is: $K_I = 96.246$ MPa/mm.
Theoretical Stress Intensity Factor obtained is: 101.50.
The percentage error is: 0.051%.
The theoretical values of Stress Intensity Factor are calculated using the following formula:

$$F_I(\lambda) = \frac{1 - 0.5\lambda + 3.6\lambda^2}{\sqrt{1-\lambda}}$$

Where,
$F_I(\lambda)$ = Ratio of theoretical to practical value of Stress Intensity Factor

Aspect Ratio (b/a)	Theoretical (Kt)	Practical (Kt)
0.3	101.50	96.246
0.2	77.519	75.826
0.1	52.290	52.021

Table -4 Stress Intensity Factor

Hence,
At lower values of aspect ratio, Stress Intensity Factor gives less error. As a result, at lower values of aspect ratio Stress Intensity Factor must be taken into account and not the Stress Concentration Factor.

IV. CONCLUSION

From the above analysis and discussion evidently conclude that ANSYS provides a very suitable way of determining stresses induced in any body. ANSYS obtained results are not very accurate as compared to the analytical results but they can be used for the simulation of complex geometries. As compared to the analytical method which only gives the numerical value of stress, ANSYS gives a more intuitive feel to the designer by displaying stress contours throughout the plate. On lower values of aspect ratio, Stress Intensity Factor gives less error. As a result, at lower values of aspect ratio Stress Intensity Factor must be taken into account and not the Stress Concentration Factor. As expected, the maximum deflection occurs when the aspect ratio of elliptical hole is 1. *i. e*. when the ellipse is a circle. The maximum stress concentration occurs at the corners of elliptical hole in all the cases.

ACKNOWLEDGEMENT

I am thankful to Prof.Vishwas B Rajyaguru, HOD Mechanical Engineering Department for his encouragement in all respect. I express my thanks to Prof. Mehul Mehta for extending his support. I would like to thank all my teaching staff, Prof.Apurv Raval, Prof.Mitesh Lalwani and others for their precious guidance and support. I would also thank to all My Friends who had helped and supported me all the time.Last but not least, the backbone of my success and confidence lies solely on the blessings of my parents.

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