International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 1, January - 2014

# Reduction in the Stress Intesity Factior for Cracks Starting from A Circular Hole in an Infinite Plate

Mr. A. A. Kshirsagar and Prof. P. R. Kulkarni

*Fracture Mechanics, Mechanical Dept.,Walchand Institute of Technology, Solapur, Maharashtra, India*

## Abstract

This paper concerns with the reduction of stress intensity factors (SIFs) of crack starting from circular hole in infinite plate subjected to internal pressure. Software 'ANSYS' is used for modeling & analysis purpose. Considering the symmetry of the model condition about the x axis and the y axis, only quarter model is prepared with 2-D solid 8 node 82 elements. Moreover, Analytical formula of the SIFs of the crack problem is examined and compared. It is found that very large reduction in the SIFs occurs due to the application of the pressure in Stress reducing feature hole near crack tip but this is applicable to the geometry where only remote load are applied.

**Keywords**
Fracture Mechanics, Cracked plate under pressure, Finite element Method, Reduction in the Stress Intensity Factor.

## 1. Introduction

During manufacturing process and fabrication sometimes cracks may appear in structural materials. Such cracks may grow in time would affect the load-bearing capacity, leading to a loss of strength and reduction in the service life of the structures; it is needed for crack to arrest to enhance residual strength and service life of the cracked structures. [1] If the structure is concerned with either static or fatigue loading, the behavior of the crack must be assessed, in order to avoid catastrophic failure. For this knowledge of the crack size, service stress, material properties and SIF (as a fundamental parameter in linear elastic fracture mechanics) are required. Fracture Mechanics is the field of mechanics concerned with the study of the propagation of cracks in materials. Hence Fracture mechanics plays an important role as it provides useful tools which allow for an analysis of materials which exhibits cracks. In a modern era, fractures have been a frequent, dangerous, and costly structural failure mode. Notable examples include collapse of aero-structures, automobile and railway bridges, pressure vessel and pipeline explosion.

## 2. Literature review

The task deals with the determination and reduction in the SIFs by various methods and a review of following papers have been studied as listed below:
Finite element Analysis combining with the concepts of linear elastic fracture mechanics provides practical and convenient means to study the fracture and crack growth of the material. 2-D FEM model is developed for two different geometries.

A rectangular plate with crack starting from a circular hole and double edge notched plate. Both geometries are in tensile loading and under mode-I conditions. In this paper a displacement extrapolation technique is employed particularly to predict the crack propagations direction and to calculate SIFs and validated with the relevant numerical and analytical results obtained by other researcher. [1]

Multiple site damage is the occurrence of small fatigue cracks at several sites within aging aircraft structures. Focusing on this typical structure, an analytical method for calculating the stress intensity factor of an infinite plate containing multiple hole-edge cracks was introduced in this paper. The properties of complex variable functions are used to evaluate the stress function. The approximate superposition method is applied to solve stress intensity factor problems on multiple holes. Few numerical examples of an infinite plate containing two hole edge cracks are examined by the method. By comparing the analytical and finite element analysis results it was realized that the analytical results are accurate and reliable. [2]

This note deals with the stress intensity factors (SIFs) of cracks emanating from a rhombus hole in a rectangular plate subjected to internal pressure by means of the displacement discontinuity method with crack-tip elements (a boundary element method) proposed recently by the author. Moreover, an empirical formula of the SIFs of the crack problem is presented and examined. It is found that the empirical formula is very accurate for evaluating the SIFs of the crack problem. [5]

Boundary value problem of a plate with crack and defect such as the circular and/or elliptical holes is a multi-connected domain problem; this kind of problem is suitable for solving by boundary element method with its higher precision. The sub-region method is used in the paper, a center cracked plate subjected to remote tensile and shear loading is studied numerically. The effect of the circular hole on Mode-I and Mode-II stress intensity factors is studied assuming the plane strain condition; the results are more precise than that of using FEM. The effect of the elliptical hole on Mode-I stress intensity factors are studied as well and some significant results are obtained. [6]

Several methods have been employed to arrest the crack growth i.e. strip or patch repaired method, Artificial crack closure by crack filling, Welding repaired, Indendation The method of external adhesive patching across the crack is commonly used in aircraft industry, bridge and civil structures. Problems of adhesive patching have been analysed analytically and numerically. Commonly, the method of complex variable formulation has been used to analyses these problems. Some conventional numerical methods such as Finite Element Method have been studied for aircraft structures using bonded composite patches. [7]

Several methods have been employed to reduce stress intensity factor i.e. stop hole drill method, crack flank holes method, cold hole expansion process. The method of drilling stop holes were drilled in front of crack tip so that the approaching crack towards the hole will get blunt and get arrested. These holes can also be cold expanded to enhance crack reinitiating time. Experimental investigation has been made on crack growth by drilling holes on crack flank side; it is shown that the crack growth can be reduced. [8]

### 2.1 Problem Definition

An infinite rectangular plate with a central circular hole & cracks emanating from the hole will be modeled. Pressure will be applied inside the hole for one case & pressure will be applied in hole as well as on crack face for the second case. Stress intensity factor will be calculated using Plane Strain Condition & for Linear Elastic Fracture Mechanics condition. Another hole near the crack tip will be tested as a stress reducing feature. Also effect of pressure applied in this stress reducing feature will be studied. Number of different parameters will be changed and its effect on SIFs will be observed.
The plate is shown as below. Pressure is applied inside the hole & also to the crack faces.

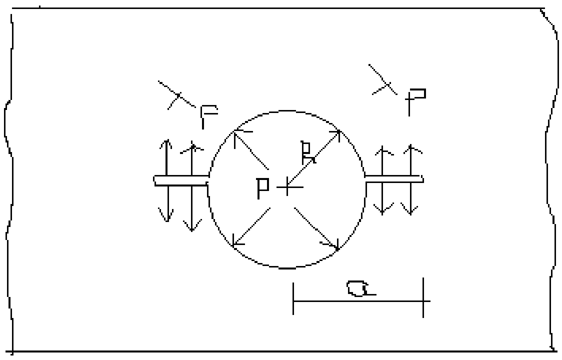


Figure 2.1 An infinite rectangular plate with central circular hole & two symmetrical cracks starting from it with pressure applied in hole & crack face

Table2.1 Geometry of the plate model (Quarter)

| | | | |
|---|---|---|---|
| **Width of the plate (mm)** | 250 | a | 25 |
| **Height of the plate(mm** | 300 | R | 20 |



## 3. Research Methodology

After the identification of the problem and after findings literature survey thus it is essential to mention the research method for the perfect solution of the problem. Analytical solution determined first and then FEM is used to solve the problem.

### 3.1Analytical Method

Stress Intensity Factor $K_I$ = F ($\lambda$,a/R) P$\sqrt{\pi.a}$ .The values of the boundary correction factor 'F' are directly available in the literatures. [3] The same are used in the present case. For this particular case i.e. for an infinite plate with hole size 20 mm & crack length 5 mm & pressure applied inside the hole & also to the crack face, the value of the BCF is 0.7929.Pressure is 200 MPa.By using the above empirical formula obtained the SIF is 1405.66 MPamm$^{½}$[4].

### 3.2 Finite Element Method

The finite element method is numerical method for solving problems of engineering and mathematical physics. It is useful for problems with complicated geometries, loading and material properties where analytical solution cannot be obtained and it is highly difficult. In such situation the numerical method (FEM) is employed. By this method we may get approximate but acceptable solution. After solve this problem byusing 'ANSYS' software, the output of the SIF is obtained.

i. e. KI = 1417.3 N $mm^{-3/2}$

% Error = $\{(K_{Ansys} - K_{Analytical}) / K_{Analytical}\}$ x 100

= {(1417.3 -1405.67) / 1405.67} x 100

= 0.827 %

The error in the finite element solution is determined by comparing the same with analytical solution obtained by using Newman's equation. The error is 0.827 % which is within acceptable range. [4]

## 4. Results and Discussions

### 4.1Reduction in the SIF by Drilling hole near to the crack tip.

An effort has been made to reduce the SIF by drilling hole near the crack tip. The effect of hole location, hole size etc. is studied during the analysis. The following table shows the various values of Stress Intensity factors for various hole locations & also for different hole sizes. As the specimen is symmetrical about both axes, only quarter model is prepared. The center of the plate is at origin i.e. at (0, 0). Accordingly the location of hole center is defined.

Table 4.2.1 Stress Intensity Factor values at different hole locations & hole sizes

| Sr. No | X mm | Y mm | Radius of Hole mm | S.I.F N-$mm^{-3/2}$ |
|---|---|---|---|---|
| 1 | 30 | 10 | 5 | 1862.5 |
| 2 | 30 | 15 | 5 | 1694.1 |
| 3 | 30 | 20 | 5 | 1590.5 |
| 4 | 30 | 25 | 5 | 1526.8 |
| 5 | 30 | 30 | 5 | 1486.2 |
| 6 | 30 | 75 | 5 | 1423.7 |
| 7 | 30 | 125 | 5 | 1419.2 |
| 8 | 30 | 150 | 5 | 1418.7 |
| 9 | 30 | 175 | 5 | 1418.5 |
| 10 | 30 | 200 | 5 | 1418.4 |
| 11 | 30 | 225 | 5 | 1418.5 |
| 12 | 30 | 225 | 5 | 1418.4 |

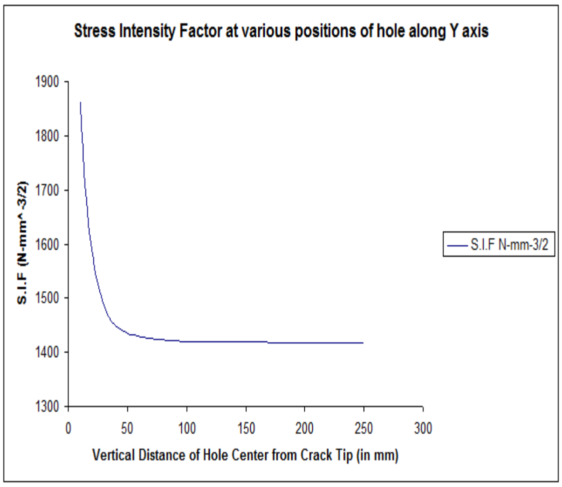


Figure 4.2.1 Stress Intensity Factor at various hole locations along Y axis

From the above analysis, the graph is plotted indicating values of SIF at various distances from crack tip along Y axis. By drilling a hole, there is increase in the value of Stress Intensity Factor instead of reduction. From the above graph it is seen that as the vertical distance of the center of hole goes on increasing initially, there is large reduction in Stress Intensity Factor.

But afterwards it is almost remaining constant. The minimum value of Stress Intensity Factor is obtained at Y= 200 mm, but the value is greater than the value without hole. i.e. this hole is becoming a defect instead of acting as a stress reducing feature.

In the above analysis, horizontal distance from the crack tip is kept constant.

Table No. 4.2.2 Pressure applied in stress reducing feature hole

| Sr. No | X mm | Y mm | Radius of Hole mm | Pressure applied in the hole for stress reduction MPa | S.I.F N-$mm^{-3/2}$ |
|---|---|---|---|---|---|
| 1 | 35 | 200 | 20 | 0 | 1416.8 |
| 2 | 35 | 200 | 20 | 25 | 1414.1 |
| 3 | 35 | 200 | 20 | 50 | 1411.5 |
| 4 | 35 | 200 | 20 | 75 | 1408.8 |
| 5 | 35 | 200 | 20 | 200 | 1395.6 |
| 6 | 30 | 50 | 5 | 25 | 1429 |
| 7 | 30 | 50 | 5 | 50 | 1424.3 |
| 8 | 30 | 50 | 5 | 75 | 1419.6 |
| 9 | 30 | 25 | 5 | 0 | 1526.8 |
| 10 | 30 | 25 | 10 | 25 | 1869.6 |

ISSN: 2278-0181
Vol. 3 Issue 1, January - 2014

Table No 4.2.3 Pressure applied in stress reducing feature hole with pressure in main hole only

| Sr. No | X mm | Y mm | Radius of Hole mm | Pressure applied in the hole for stress reduction MPa | S.I.F N-mm$^{-3/2}$ |
|---|---|---|---|---|---|
| 1 | 30 | 10 | 5 | 0 | 985.18 |
| 2 | 30 | 100 | 5 | 0 | 614.91 |
| 3 | 30 | 150 | 5 | 0 | 613.50 |
| 4 | 30 | 150 | 5 | 100 | 610.68 |
| 5 | 30 | 150 | 15 | 0 | 615.36 |
| 6 | 30 | 175 | 15 | 100 | 620.34 |
| 7 | 30 | 175 | 20 | 0 | 621.30 |
| 8 | 30 | 200 | 20 | 100 | 620.20 |

The trial of reduction in the SIFs also done by considering pressure in the main hole only & not to the crack face & for various hole locations. Thus from all the above trials it is seen that there is very slight reduction in the S.I.F. due to the hole as a stress reducing feature. Also there is very less far reduction in values of S.I.F. by applying the pressure in the stress reducing feature.

Thus hole as a stress reducing feature fails almost completely. Also the pressure applied in this feature is failing to reduce the values of S.I.F. To confirm that there is no effect of pressure applied in the stress reducing feature 'hole', further, study is done for uniaxial tensile loading instead of pressure applied in the main hole & crack face.

Crack length of 5 mm was considered for this study. The normal value of S.I.F. for this geometry under a remote tensile stress of 200 MPa is calculated using Boundary Correction Factors available in the literatures. BCF is 1.0168. [3]

$K_1 = F(\lambda, a/R)\, \sigma \sqrt{\pi . a}$

$= 1.0168 \text{ X } 200 \text{ X } \sqrt{3.14x25}$

$= 1802.59$ N-mm$^{-3/2}$

The stress reducing feature hole is now given different location & radius & study is done.
The output is as follows.

Table No.4.2.4Trial of reduction of S.I.F. for remote tensile loading

| Sr. No | X mm | Y mm | Radius of Hole mm | S.I.F N-mm$^{-3/2}$ |
|---|---|---|---|---|
| 1 | 30 | 10 | 5 | 2211.3 |
| 2 | 30 | 15 | 5 | 1964.4 |
| 3 | 30 | 50 | 5 | 1814.17 |
| 4 | 30 | 60 | 5 | 1812.8 |
| 5 | 30 | 65 | 5 | 1812.3 |
| 6 | 30 | 70 | 5 | 1815.4 |
| 7 | 30 | 75 | 5 | 1815.1 |

Table No.4.2.5 Effect of hole size on values of S.I.F.

| Sr. No | X mm | Y mm | Radius of Hole mm | S.I.F N-mm$^{-3/2}$ |
|---|---|---|---|---|
| 1 | 30 | 65 | 5 | 1812.3 |
| 2 | 30 | 65 | 10 | 1752.9 |
| 3 | 30 | 65 | 20 | 1517.8 |
| 4 | 30 | 65 | 25 | 1283.9 |

As there is very less reduction in S.I.F. at higher values of vertical distance, the hole size is now increased to check further reduction of SIFs.

The following figure shows the arrangement of 4$^{th}$ reading of table No. 4.2.5

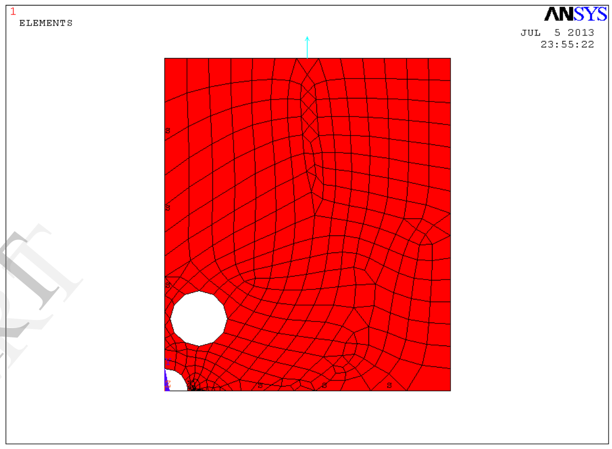


Figure 4.2.2 Model with load & boundary condition for X=30mm, Y=65mm & Radius of hole=25

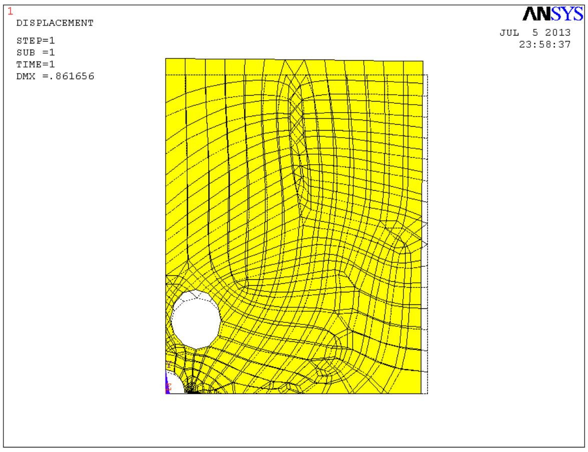


Figure 4.2.3 Deformed shape for the condition for X=30mm,Y = 65mm & Radius of hole = 25 mm

## 4. 2 Stress reducing feature hole

Now the pressure is applied in the stress reducing feature hole & its effect is observed.

Table No. 4.1 Effect of presser applied in the Stress Reducing Feature hole

| Sr. No | X mm | Y mm | Radius of Hole mm | Pressure applied in the hole for stress reduction MPa | S.I.F N-mm$^{-3/2}$ |
|---|---|---|---|---|---|
| 1 | 30 | 65 | 25 | 50 | 1029.31 |
| 2 | 30 | 65 | 25 | 75 | 901.52 |
| 3 | 30 | 65 | 25 | 100 | 774.05 |
| 4 | 30 | 65 | 25 | 125 | 646.58 |
| 5 | 30 | 65 | 25 | 150 | 519.11 |
| 6 | 30 | 65 | 25 | 175 | 391.64 |
| 7 | 30 | 65 | 25 | 200 | 264.16 |

Thus it is seen that there is very large reduction in the Stress Intensity Factor due to the application of the pressure in the Stress Reducing Feature Hole near the crack tip. But this is applicable to the geometries where only remote loads are applied.

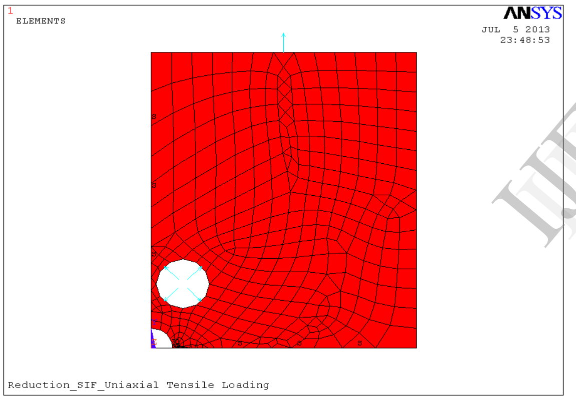


Fig.4.1 Model with largest reduction in Stress Intensity Factor

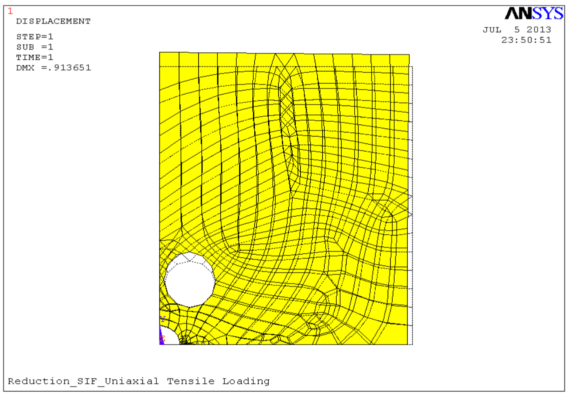


Fig.4.2 Deformed shape of model with hole for largest reduction in SIF

After solving this problem by solver, the output of the SIF is obtained i.e.**KI = 264.16 N-mm$^{-3/2}$** for the condition for X= 30mm, Y=65mm and Radius of hole =25mm.

In normal condition i.e. without introducing stress reducing feature hole the SIF is 1802.59 N-mm$^{-3/2}$ whereas with introducing stress reducing feature hole the SIF is 1283.9 N-mm$^{-3/2}$. It is observed that very large reduction in the Stress Intensity Factor due to the application of the pressure in the Stress Reducing Feature Hole near the crack tip i.e. SIF is 264.16 N-mm$^{-3/2}$.But this is applicable to the geometries where only remote loads are applied.

## 5. Conclusions

The two-dimensional studies carried out for an infinite plate with a central circular hole & symmetrical cracks emanating from the hole. Pressure was applied in the hole in one case & to the hole& crack face also for the second case. Plane 82 elements are used in the analysis. A stress reducing feature hole is used to reduce the stress intensity factor. Also pressure was applied in this hole for reduction in stress intensity factor.

The conclusions drawn from the analysis carried out are as follows:-

- Improper location of stress reducing feature hole leads to increase in Stress Intensity Factor.
- Reduction in Stress Intensity Factor can be done by drilling holes at proper locations. But this is possible only for remote loading.
- Applying pressure in a hole to be used as stress reducing feature leads to further reduction of Stress Intensity Factor.

## 6. Future scope

The following are the future scope associated with the current research work this work.

- Investigation of new location of holes & sizes leading similar reduction of Stress Intensity Factor.
- Study of behavior of same plate but with finite geometry & biaxial loading.

## Acknowledgement

It gives me great satisfaction in presenting this paper on the title "Reduction in The Stress Intensity Factor for Cracks Starting from A Circular Hole in An Infinite Plate".

I would like to take this opportunity to express my deep gratitude to my guide Prof. P.R. KULKARNI for his valuable guidance and moral support throughout this successful completion of this paper. We are thankful to Prof. K.H. JATKAR, Head –Mechanical Engineering for giving us an opportunity to present our paper.

## References

1. MiloudSouiyah, AbdulnaserAlshoaibi. et al, Stress intensity factor Evaluation for crack Emanating from circular hole using Fnite element method, International review of mechanical engineering. 2 (2008) 25- 50
2. Jinfang Zhao, LiyangXie, et al, A method for stress intensity factor calculation of infinite plate containing multiple hole-edge cracks. International journal of fatigue 35 (2012) 2-9
3. G. C. Sih, Handbook of Stress Intensity Factor “S.I. F. Solutions & Formulas”, Bethlehem Institute of Structure & Solid Mechanics.
4. Kshirsagar A.A, P.R.kulkarni, Finite Element Analysis of Cracks Starting From A Circular Hole Under Pressure, International journal of advances in management, technology &Engineering sciences vol. 2,(2013) 27-31
5. Xiangqiao Yan, Cracks emanating from a rhombus hole in infinite and finite plate subjected to internal pressure, Engineering Failure Analysis, 14,(2007) 548–556
6. Junping PuEffect of defective holes on crack using the boundary element method, Engineering Analysis with Boundary Elements, 30 (2006) 577–581
7. G.A.Papadopoulos, B.Badaloukaandj, “Experimental Study of the Reduction at Crack Tip Stress Intensity Factor $K_I$ by Bonded Patches”, SouyiannisIntJFract, 2008
8. S.T. Pinho, H.B. Martins, P.P. Camanho, M.H. Santare, “Residual Stress Field & Reduction of Stress Intensity Factor in Cold Worked Holes”, IntJFract, May 2009