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Parametric Study Of Stress Concentration Factor For Thin Plate Using Finite Element Analysis

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Abstract

A thin plate is considered for the study of stress concentration. ANSYS software is used for finite element analysis. Since plate thickness is small as compared to cross sectional area & loading is in the plane of the plate, it is treated as a 'Plane Stress' condition. Maximum stress occurs at the smallest cross section. Analytical calculation is done by applying the theory of combined tensile and bending stress theory. Local high stress value at the notch is obtained from ANSYS plane stress model. APDL is used for running finite element simulation, since the program can be easily modified for various parameters. Results of the parametric study indicate that stress concentration factor is independent of the thickness of the plate but it increases as the notch radius is reduced.

Nomenclature:

K_t : Stress concentration factor
P : Force
A : Area of cross section
M : Bending moment
I : Moment of inertia
Y : Maximum distance of a fiber from neutral axis
σ_t : Tensile stress
σ_{nom} : Nominal stress
σ_{max} : Maximum stress

1 Introduction

Equations used to calculate bending stress, tensile stress, torsional stress etc are based on the assumption that there are no discontinuities in the cross section of the component. In practice, discontinuities and abrupt changes of cross section are present due to oil holes and grooves, keyways and splines, screw threads and shoulders etc. The assumption of a uniform cross section cannot be made under these circumstances and the elementary equations do not give correct results. A plate with a small circular hole is shown in the figure 1.

It is observed that the nature of stress distribution at the section passing through the hole that there is a sudden rise in the magnitude of stresses in the vicinity of the hole. The localised stresses in the neighbourhood of the hole are far greater than the stresses obtained by the elementary equations.

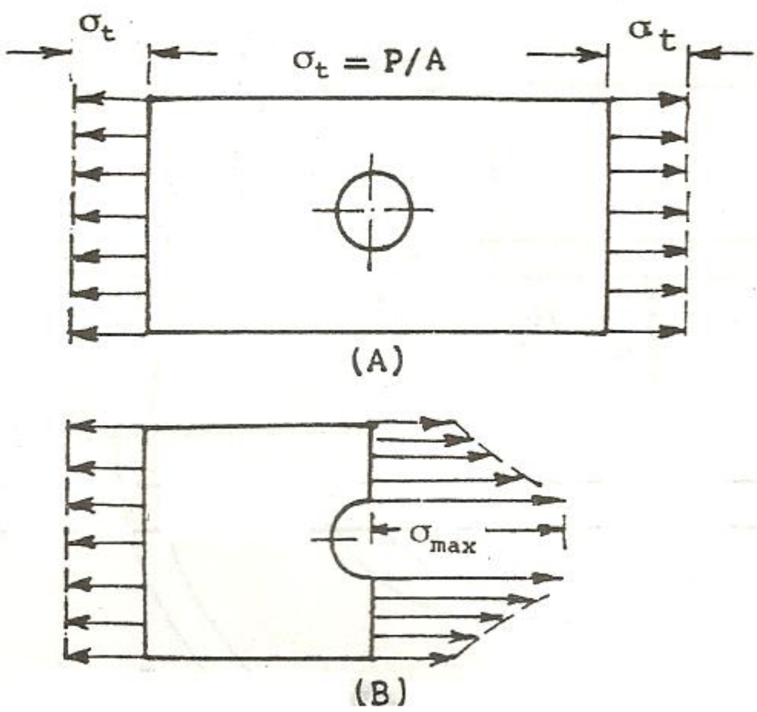

Fig 1

Stress concentration is defined as the localisation of high stresses due to irregularities or abrupt changes of the cross section. The stresses obtained by the elementary equations are modified to account for the stress concentration.

Stress concentration factor K_t is defined using equation 1 as

$$K_t = \frac{\textit{Highest value of actual stress near discontinuity}}{\textit{Nominal stress obtained by elementary equation for minimum cross section}} \quad \text{..........} \qquad (1)$$

Irregularities in the cross section can be due to

(a) A metallurgical processes (as inclusions, blowholes, laminations, quenching cracks, etc.)

(b) A mechanical notch, of some geometrical type which usually results from a machining process (as grooves, holes, threads, keyways, fillets, serrations, surface indentations)

(c) A service notch, which is formed during use (as chemical or corrosion pits, scuffing, chafing or fretting, impact indentations, and so on).

Load carrying capacity of a material is affected in actual machine parts because of the presence of these irregularities.

This paper intends to study the effect of various parameters on stress concentration factors of a thin plate using finite element analysis

2 Problem Formulation

A thin plate with dimensions shown in figure 2 is considered for the purpose of study. Load of 3500N is applied at two holes as shown. Value of E (Young's modulus) is taken as 21000MPa & Poisson's ratio as 0.33. Plate thickness is 2 mm.

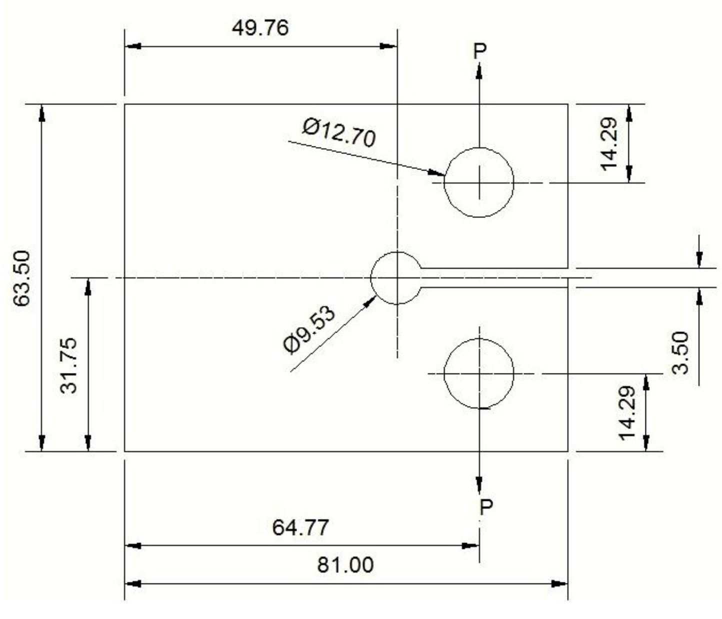

Fig 2

Methodology used is as follows

2.1 Theoretical Calculations

Section (A-A) is considered for calculations purpose as shown in figure 3.

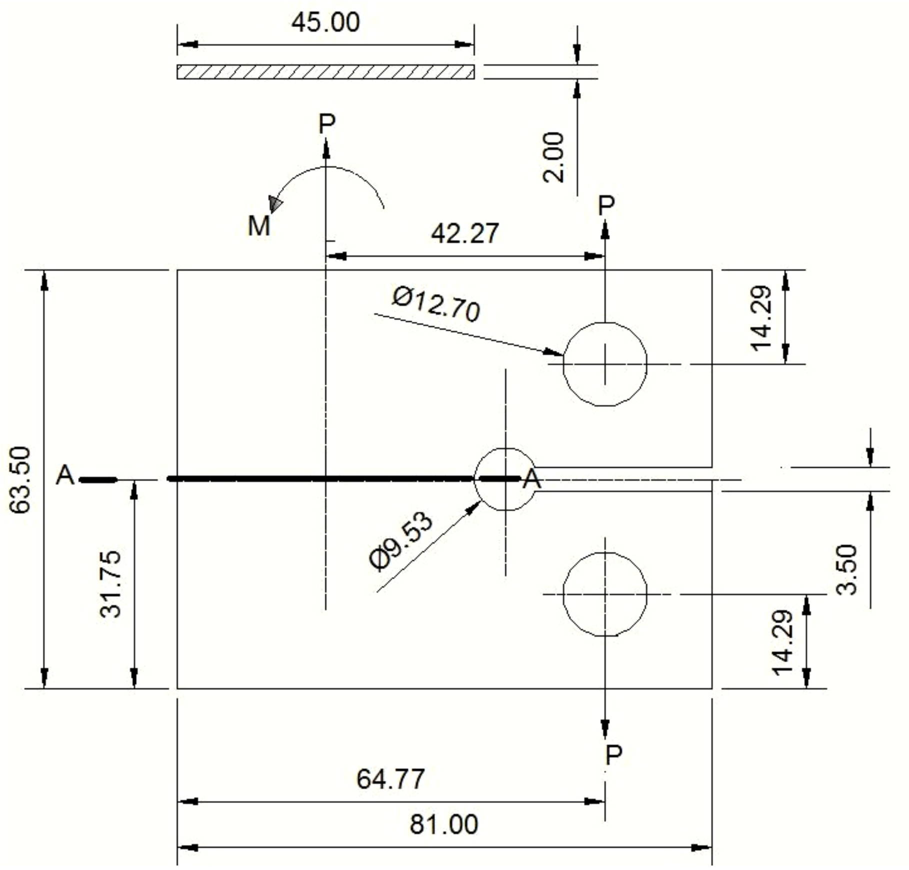

Fig 3

This section is considered because it is the weakest section of the specimen. Therefore maximum stresses will be developed in this section.

Combined axial stress plus bending stress due to the moment M as shown in figure 3 is calculated theoretically.

2.2 Stress calculation using FEM

Since the thickness of the plate is very small as compared to other dimensions & since the load is applied perpendicular to the cross section, it is considered as Plane Stress condition.

FE Model is developed using ANSYS software. Plane type element ‘Plane 82’ is used for meshing purpose.

3 Problem Solution

3.1 Theoretical Calculations:

Tensile stress due to axial load is calculated as per equation 2

$$\sigma_t = \frac{P}{A} \quad \ldots\ldots \quad (2)$$

$$= \frac{3500}{45*2}$$

= 38.88 MPa

Bending stress is calculated as per equation 3

$$\text{Bending Stress} = \frac{M*y}{I} \quad \ldots\ldots \quad (3)$$

$$\sigma_b = \frac{(3500*42.3)*22.5}{2*(45)^3/12}$$

= 219.33 MPa

Nominal stress is calculated as per equation 4

Nominal Stress: $\sigma_{nom} = \sigma_t + \sigma_b$ .. (4)

σ_{nom} = 38.88 + 219.33

= 258.21 MPa

3.2 Finite Element Calculations using ANSYS:

This is treated as plane stress problem with specified thickness. Therefore keyopt = 3

Part is symmetric about A-A. Therefore symmetry boundary condition is applied. Program is written using ANSYS Parametric Design Language (APDL).

A plot of meshing with symmetry boundary condition is shown below in fig 4.

Point load creates stress singularity; therefore load is applied as equally distributed load along the semi circular periphery of the hole.

A plot of equivalent stress is obtained as shown in fig 5

Maximum stress occurs near the hole as shown by the plot of nodal stresses in Fig 6

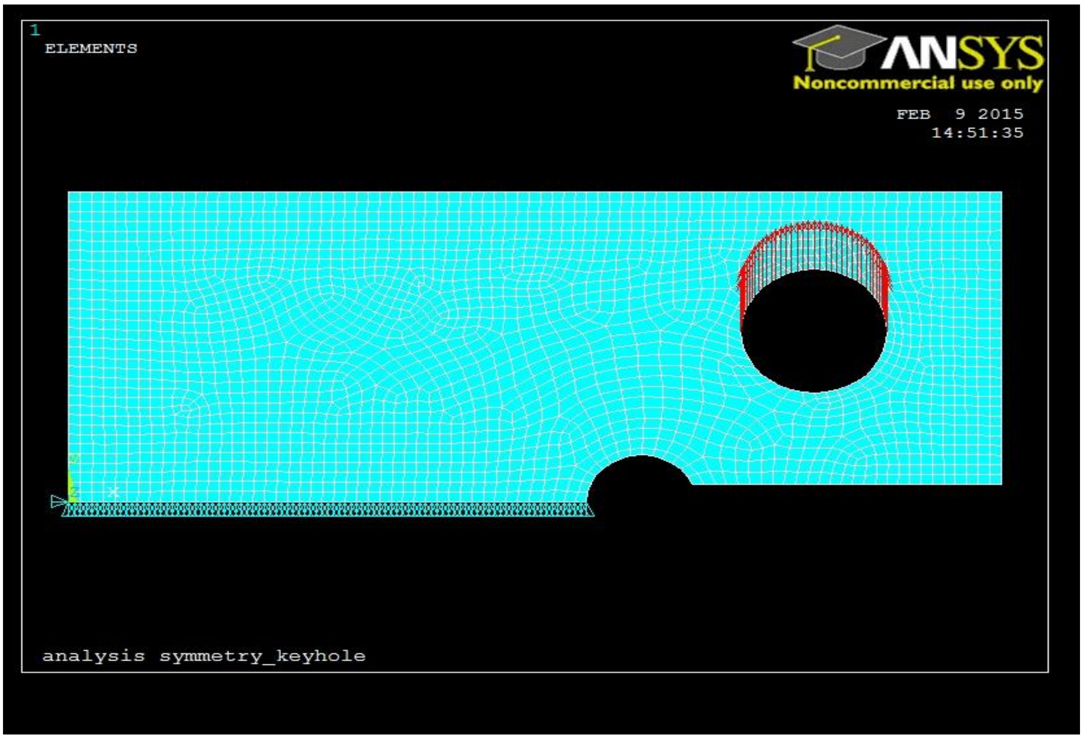

Fig 4- Meshing of the model

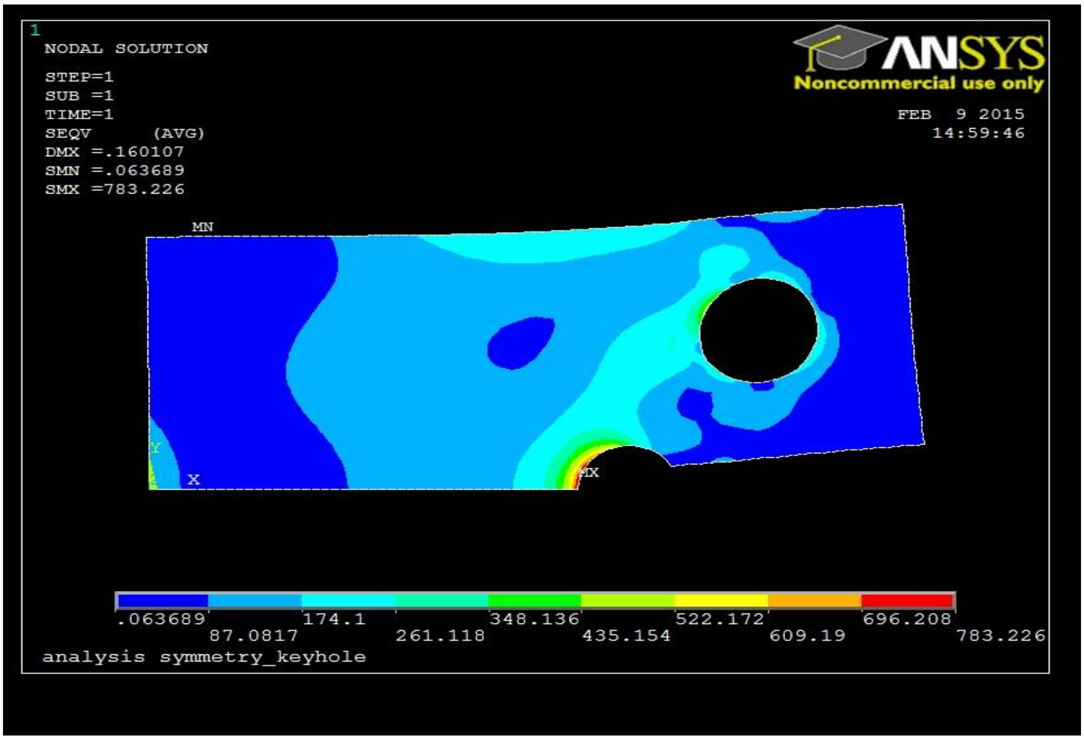

Fig 5- Plot of nodal stresses

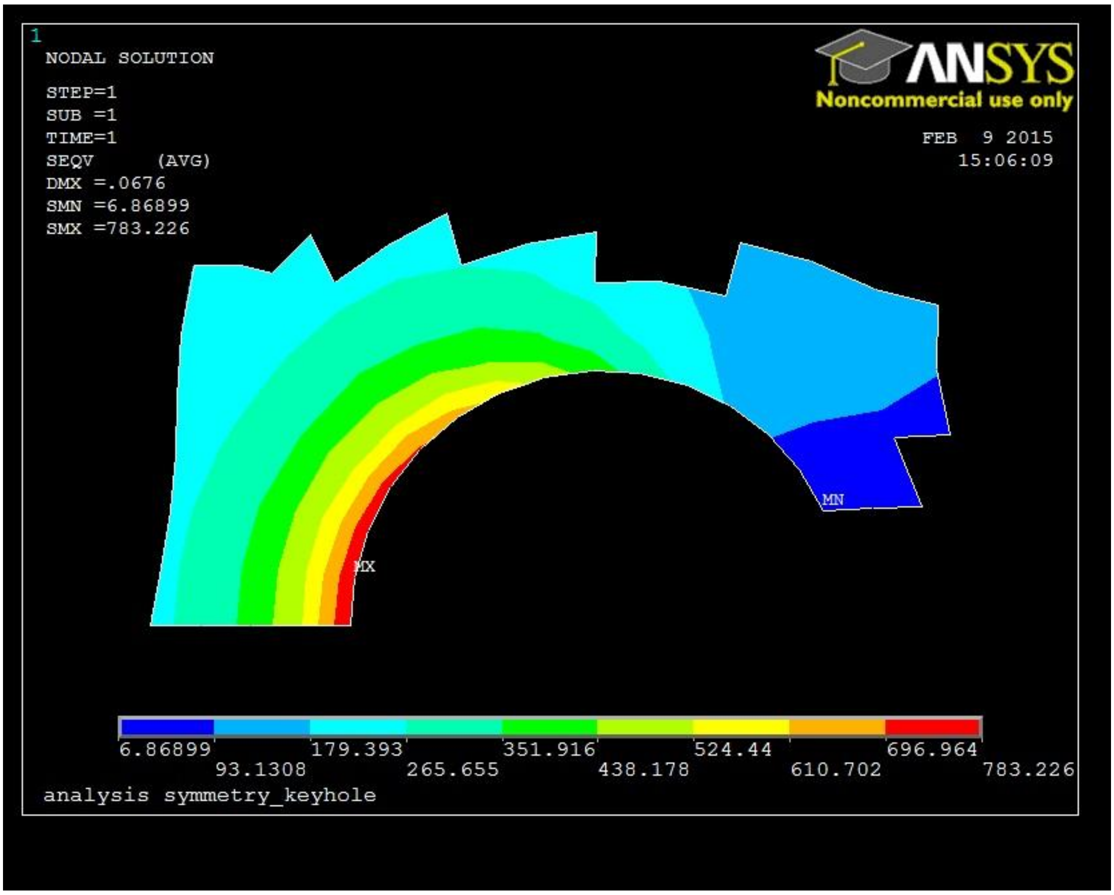

Fig 6- Plot of maximum nodal stress

Maximum stress obtained in the red zone is
σ_{max} = 783.22MPa (from ANSYS results as shown in figure 6)

Therefore

Stress Concentration Factor $= \dfrac{\sigma_{max}}{\sigma_{nom}}$ ….. (5)

= 3.03

3.3 Parametric Study:

3.3.1 Plate thickness is varied by keeping other dimensions same. Notch Radius = 4.765 mm

Case 1:

Plate Thickness = 2 mm
σ_t = 38.88 MPa
σ_b = 219.33MPa

Nominal Stress from equation 4 is

σ_{nom} = 258.21 MPa

σ_{max} = 783.22MPa (from ANSYS results as shown in figure 6)

Therefore from equation 5

Stress Concentration Factor =3.03

Case 2:

Plate Thickness = 3 mm

σ_t = 25.92 MPa

σ_b = 146.22MPa

Nominal Stress from equation 4 is

σ_{nom} = 172.14

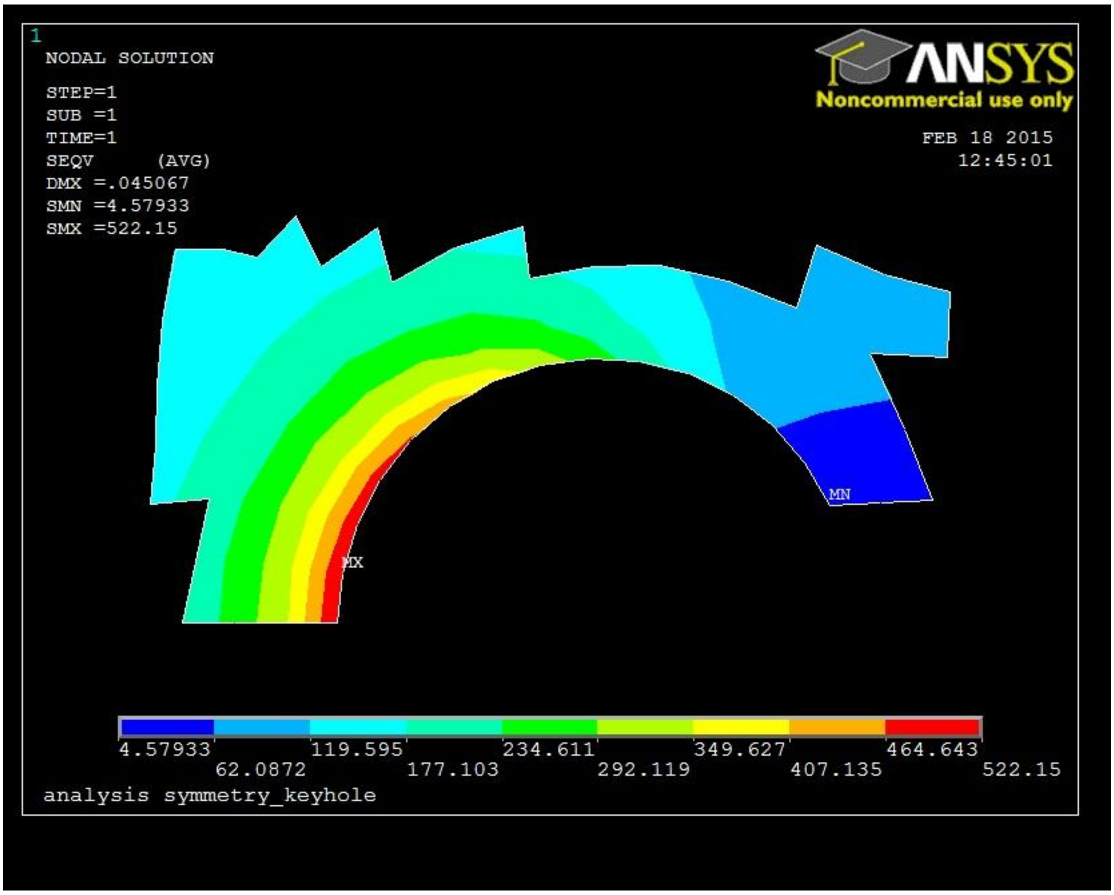

Fig 7- Plot of maximum nodal stress

σ_{max} = 522.15 (from ANSYS results as shown in figure 7)

Therefore from equation 5
Stress Concentration Factor = 3.03

Case 3:
Plate Thickness = 4 mm
σ_t = 19.44 MPa
σ_b = 109.66MPa

Nominal Stress from equation 4 is
σ_{nom} = 129.11

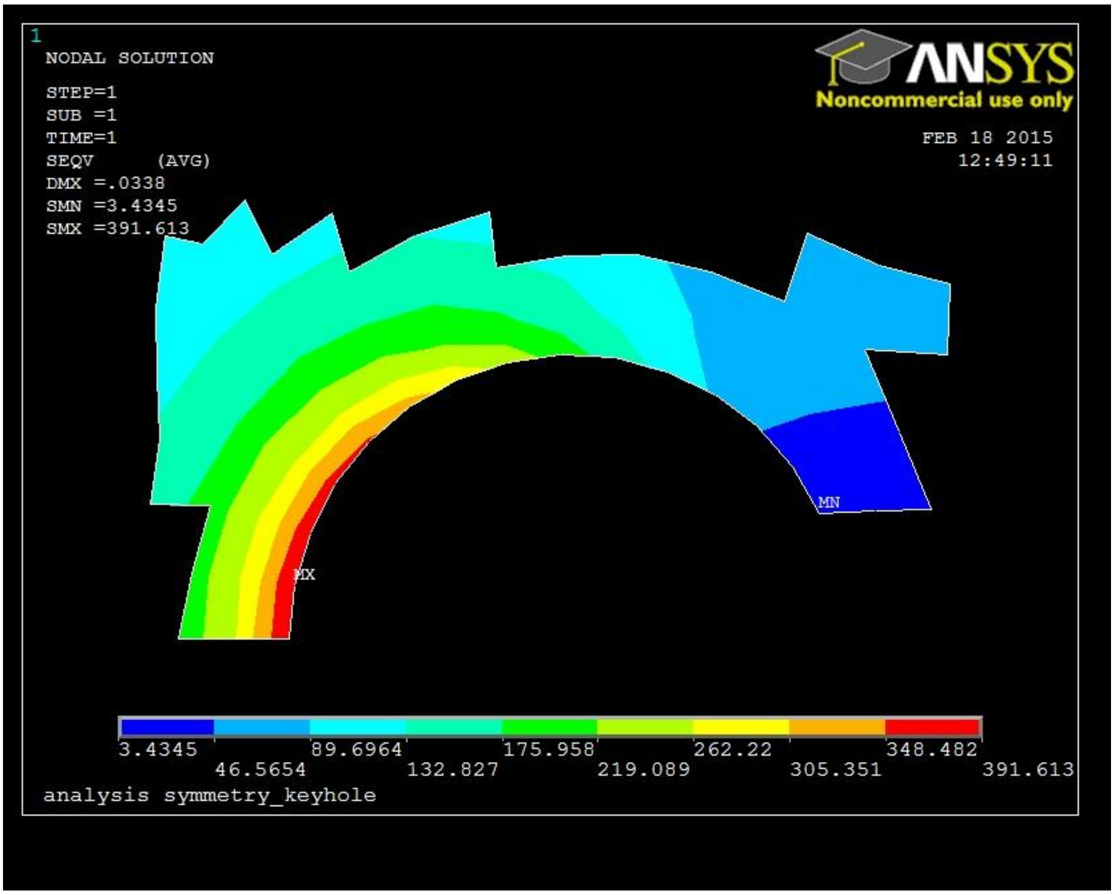

Fig 8- Plot of maximum nodal stress

σ_{max} = 391.63 (from ANSYS results as shown in figure 8)
Therefore from equation 5
Stress Concentration Factor = 3.03

3.3.2 Plate thickness is kept constant as 2mm and the notch radius is changed

Case 4:

Notch Radius = 4.765 mm
Stress Concentration Factor = 3.03

Case 5:

Notch Radius = 4.0 mm
σ_t = 38.24 MPa
σ_b = 206.56 MPa

Nominal Stress from equation 4 is
σ_{nom} = 244.80 MPa
σ_{max} = 824.38 (from ANSYS results as shown in figure 9)

Therefore from equation 5
Stress Concentration Factor = 3.36

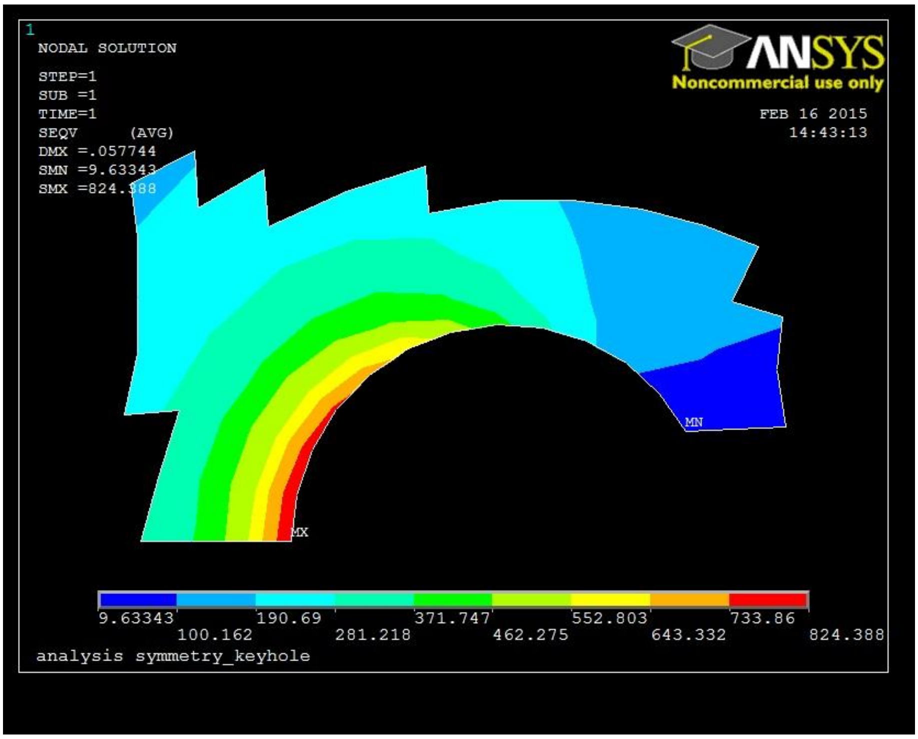

Fig 9- Plot of maximum nodal stress

Case 6:

Notch Radius = 3.5 mm
σ_t = 37.82 MPa
σ_b = 204.3 MPa

Nominal Stress from equation 4 is
σ_{nom} = 242.12 MPa

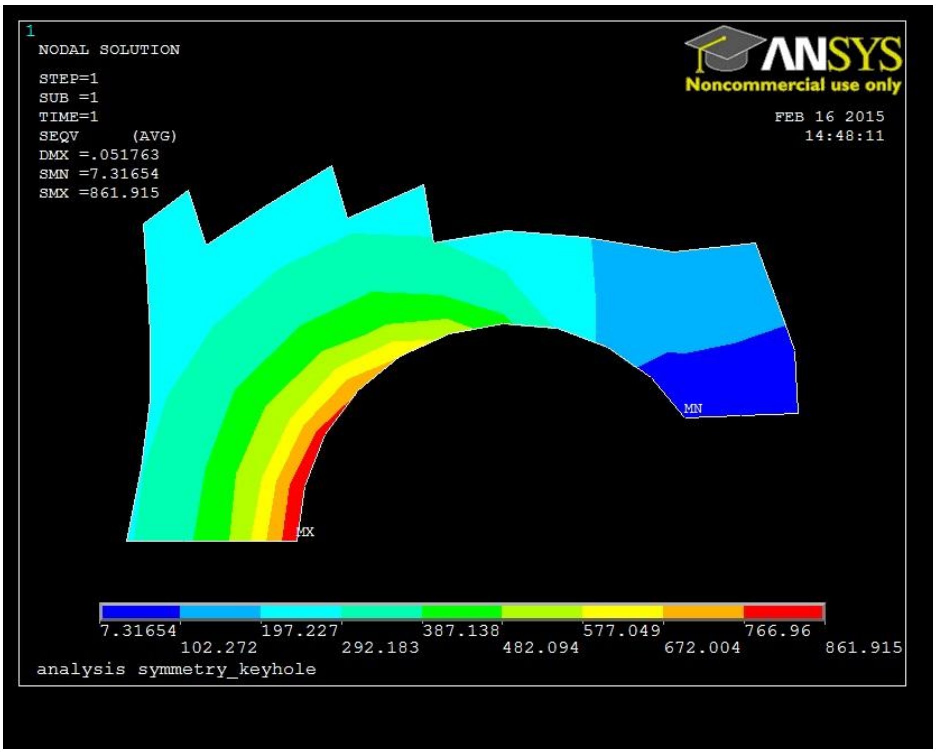

Fig 10- Plot of maximum nodal stress

σ_{max} = 861.92 (from ANSYS results as shown in figure 10)
Therefore from equation 5
Stress Concentration Factor = 3.56

Case 7:
Notch Radius = 3.0 mm
σ_t = 37.42 MPa
σ_b = 198.76 MPa

Nominal Stress from equation 4 is
σ_{nom} = 236.18 MPa
σ_{max} = 912.73 (from ANSYS results as shown in figure 11)

Therefore from equation 5
Stress Concentration Factor = 3.86

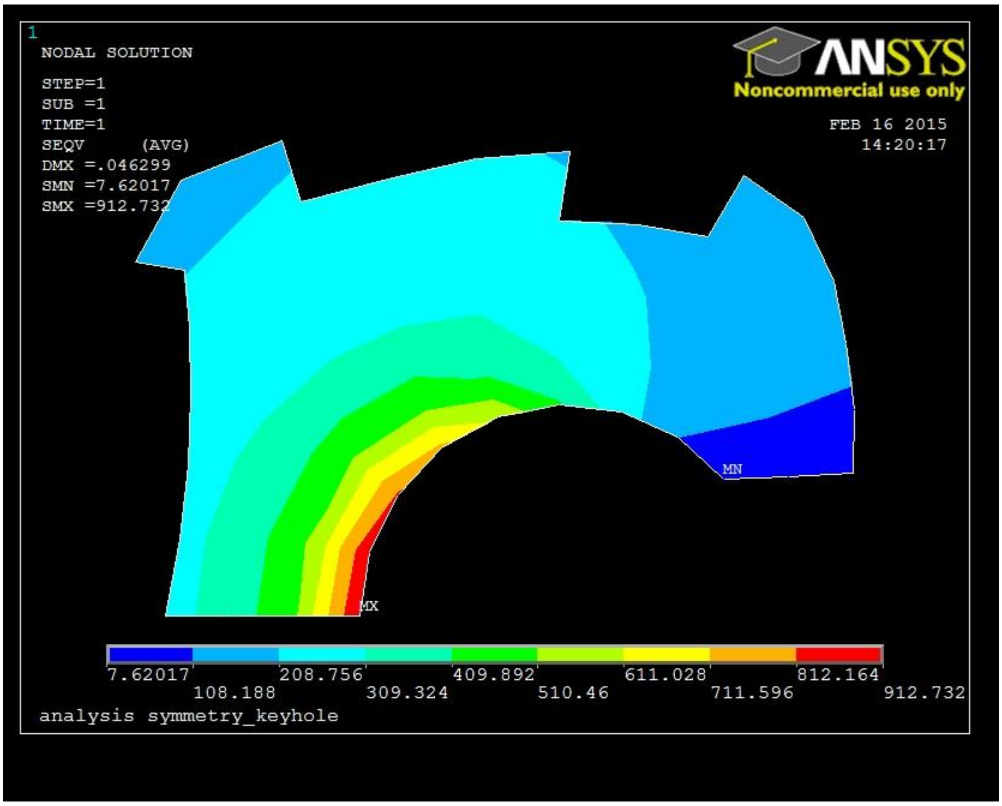

Fig 11- Plot of maximum nodal stress

4 Results and Discussions

4.1 Effect of plate thickness variation on stress concentration factor keeping all other dimensions same is shown in Table 1.

Table 1

Sr No	Plate Thickness (mm)	Notch Radius (mm)	Stress Concentration Factor
1	2	4.765	3.03
2	3	4.765	3.03
3	4	4.765	3.03

It is observed from the table that variation in the plate thickness has no effect on the stress concentration factor.

4.2 Effect of notch radius variation on stress concentration factor keeping the plate thickness constant is shown in Table 2

Table 2

Sr No	Plate Thickness (mm)	Notch Radius (mm)	Stress Concentration Factor
4	2	4.765	3.03
5	2	4.0	3.36
6	2	3.5	3.56
7	2	3.0	3.86

It is observed that the notch radius has a significant effect on the stress concentration factor. As the notch radius is reduced, stress concentration factor increases.

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5. Conclusion

This method can be used for any complex geometry since complex models can be created using CAD 3D modeling softwares. These models can be imported in finite element analysis softwares and complex loading conditions can be imposed to get the value of maximum stress at the discontinuity since these softwares are capable of handling any of complex problems. This paper demonstrates the use of finite element technique to calculate the stress concentration factor.

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