Impact Factor (SJIF): 4.542

International Journal of Advance Research in Engineering, Science & Technology

e-ISSN: 2393-9877, p-ISSN: 2394-2444

Volume 4, Issue 8, August-2017

CRITICAL STUDY OF STRESS CONCENTRATION AROUND DIFFERENT CUT-OUTS IN PERFORATED BEAM

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Abstract ***—Perforated beams i.e. steel and aluminum beams with cut-outs are extensively used in structural application due to its aesthetics, versatility, economy and ease of use. The present research work is focused on Finite Element Analysis of perforated beam. The prime objective is to study the impact of cut-out on stress concentration of perforated beam. The beam with cut-outs are widely used in structural members. These cut-outs induces stress concentration in beam. This work aims to analyse the static analysis of an isotropic rectangular beam with various boundary conditions and load applications. This work is helpful in obtaining the results at the node points as well as the entire surface of the rectangular beam. A Rectangular cantilever beam is considered with different shapes of cut-outs such as, circular, elliptical, square, blunted square and triangular. The main objective of this study is to find out the stress concentration in beam around various cut-outs. In this, finite element analysis has been carried out using software ANSYS. In this study, four parameters are used as the shape of cut-out, the bluntness, the rotation of cut-out and various thicknesses of beam (6, 8, 10mm). The study will be carried out for Steel & Aluminum beam. Finally, comparison between the results of SCF obtained by ANSYS and analytically for a beam having single circular cut-out gives maximum 1.71% difference.***

For modelling, analysis tool Finite Element Analysis (FEA) software 16.0 is used.

Keywords- rectangular cantilever beam, isotropic material, stress concentration factor, finite element analysis, von misses stresses, shape of cut-out.

I. INTRODUCTION

It is important to study the effects of stress raisers such as notches, holes, and sharp corners in machine members. Such discontinuities can cause a large rise in stress above the nominal stress or the nominal value. This issue is addressed through numerical method as well as theoretical method. The numerical method is based on a finite element solution. in a tensile specimen, a discontinuity such as circular hole is a stress raiser, and its effect on the stress is through a stress concentration factor. Similarly, a circular hole drilled through a beam loaded in compression is also a stress raiser with its own stress concentration factor. In this study, the stress concentration factor for a cantilever beam with holes under tensile loading conditions is compared by analytically and by ANSYS for single circular cut-out. Then the solutions by ANSYS for the stress concentration factors for the specimens having 3 series of various shapes of cut-outs are conducted using Finite element analysis. Different shapes of cut-outs such as, circular, elliptical, square (without rotation and with rotation at 15°, 30° & 45°), blunted square (with bluntness of 1mm radius for all four corners) and triangular (with rotation at 0°, 15° & 30°) cutout(s).

The finite element method is being used in virtually every engineering discipline. The aerospace, automotive, biomedical, chemicals, electronics, energy, geotechnical, manufacturing, and plastics industries routinely apply finite element analysis. In addition, it is not only used for analysing classical static structural problems, but also for such diverse areas as mass transport, heat transfer, dynamics, stability, and radiation problems.

For static structural problems ANSYS is having two modules one is Mechanical APDL and another is ANSYS Workbench. Both modules give accurate results but both are having their own advantages and disadvantages. Mechanical APDL is very complex and vast module as it provides more control to user rather than to software to control the analysis where in case of Workbench control on analysis is less compare to APDL but Workbench provides more realistic visual simulation compares to APDL. Even APDL is time consuming module compare to workbench. So, for more complex problems APDL is used and for less complex problems which requires visual simulation workbench is used. So, for modelling of beam it looks like workbench will be good choice as it doesn't involve any complex inputs and requires visual simulation. In this thesis workbench is chosen over APDL and in work bench static structural module is selected to model beam.

II. ANALYSIS OF BEAM WITH CUT-OUT *(validation problem)*

Analytical method for computation of stress concentration is shown as follows. The same method has been followed for analysis of cantilever beam having different cut-outs. Here sample calculation for case-I is shown. We shall carry out the analysis for six different cases.

INPUT DATA

1. Length of beam ………………………. 300mm.
2. Width of beam ………………………... 50mm.
3. Thickness of beam……………………. 6, 8 and 10mm.

Cut -outs dimensions

1. Circular Cut-out ………………… 10mm diameter.
2. Elliptical Cut-out………………… 10mm major & 5mm minor axis.
3. Square Cut-out …………………...all sides are equal (5mm)
4. Blunted Square Cut-out............ all angles are blunted with 1mm radius
5. Triangular Cut-out.................... Inscribed triangle with 5mm radius

Geometrical model

In this project work to study the elastic stresses and behaviour of mechanical component with discontinuity in geometry subjected to different loading conditions is very important for safe life of component. Figure 1 shows geometrical modelling of component with hole and Table 1 shows the material properties details. The safe applied load can be calculated by using the following equations.

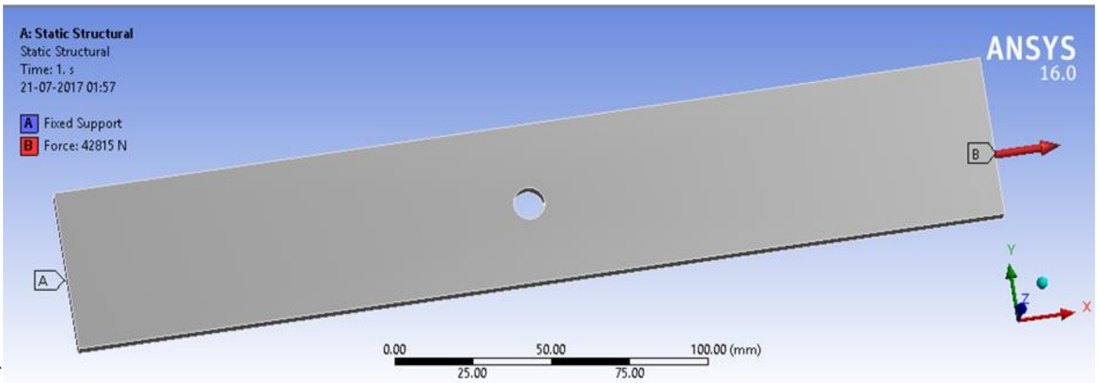


Figure 1. Plate with center Circular Cutout (6mm thickness)

Table 1. Material properties

No.	Material name	Yield Strength (MPa)	Young's Modulus (GPa)	Poisson's Ratio (µ)	Applications
1	Aluminum	290	72	0.33	Used in fuselage and wing of rivets
2	Steel	250	200	0.30	Aircraft arrestor hook under carriage

DIFFERENT CASES
CASE – I : (Validation problem) Beam having single circular cut-out
CASE – II : Beam having 3 series circular cut-outs
CASE – III : Beam having 3 series square cut-outs
CASE – IV : Beam having 3 series blunted square cut-outs
CASE – V : Beam having 3 series square cut-outs with rotation of 15°, 30°, 45°
CASE – VI : Beam having 3 series elliptical cut-outs
CASE – VII: Beam having 3 series triangular cut-outs with rotation of 0°, 15°, 30°

Cantilever beam for case – I (validation problem)

Calculation for safe applied load

$\sigma_d = \frac{Applied\ load}{Net\ area}$ N/mm^2

$\sigma_d = \frac{Yield\ strength\ of\ material}{FOS}$ N/mm^2 Where, FOS = 1.5

Net area = (Area of plate – Area of cut-out) mm^2

Stress concentration factor (Theoretically) K_t

$$K_t = 3.00 - 3.13\left(\frac{2r}{D}\right) + 3.66\left(\frac{2r}{D}\right)^2 - 1.53\left(\frac{2r}{D}\right)^3$$

$$\sigma_{nom} = \frac{P}{t(D-2r)} \quad \text{and} \quad \sigma_{max} = K_t * \sigma_{nom}$$

Where, r = Radius of cut-out
D = Width of section
t = Thickness of plate
P = Applied load
σ_{nom} = Nominal stress
σ_{max} = Peak stress

Table 2. SCF for Aluminum and Steel Alloy tensile loading for single circular cut-out

Material	Thickness of plate (mm)	Maximum Stress σmax N/mm²	SCF K by ANSYS (FEA)	SCF by Analytically	SCF From Literature	% Difference
Aluminum	6	447.68	2.509	2.508	2.38	0.22
	8	480.25	2.472	2.508	2.44	1.40
	10	504.74	2.477	2.508	2.45	1.19
Steel	6	386.11	2.510	2.508	2.45	0.11
	8	412.69	2.464	2.508	2.44	1.71
	10	434.50	2.474	2.508	2.45	1.33

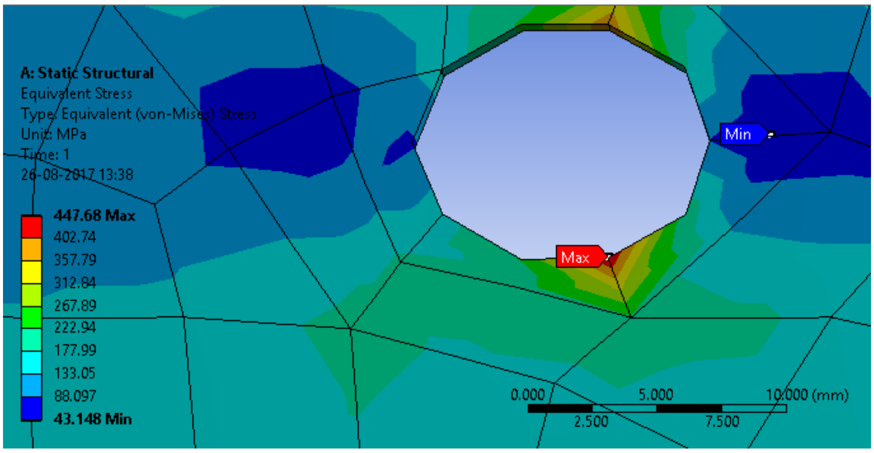


Figure 2. **FEA Results for 6mm thick Aluminum beam having circular cut-out with tensile loading.**

Comparison of analytical and ANSYS outputs

By comparing the analytical and Ansys results it is found that the results given by Ansys are nearly same for all the size of the beams subjected to loading and support conditions. The results fairly match for stress concentration and so we can say Ansys can be further used for complex structures and fairly accurate results can be expected.

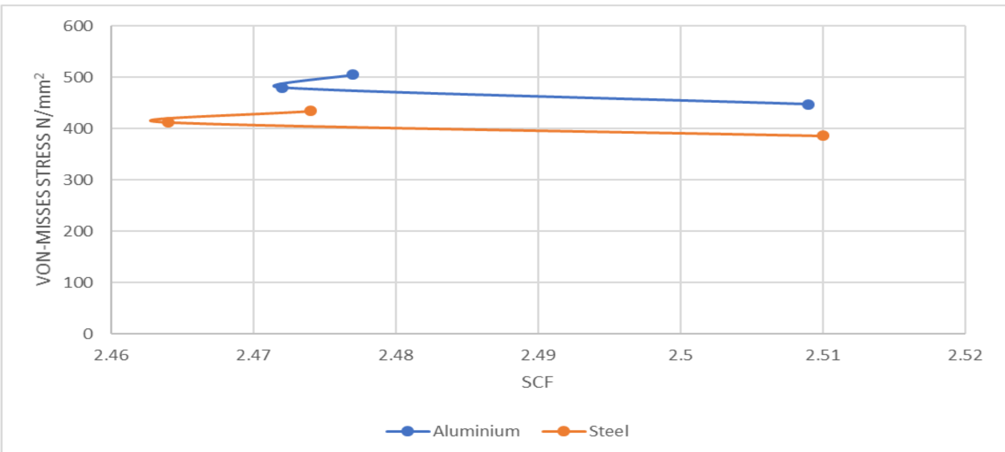


Figure 3. Graph of Von-Misses stress v/s SCF for Aluminum & steel with Circular cut-out at t = 6, 8, 10mm

III. ANALYSIS OF BEAM WITH 3 SERIES OF CUT-OUTS

A. Beam having 3 series of circular, square, blunted square and elliptical cut-outs

A beam (aluminum and steel) with fixed end support having spans 3m was considered to be loaded with calculated tensile load. 3 series of different shapes cut-outs were considered; circular, square, blunted square and elliptical, where dimensions of these cut-outs were considered as per given before. Different thicknesses of beam like, 6mm, 8mm and 10mm were considered for analysis. The parameters of the beam studied were maximum principal stress, von misses stress, and stress concentration factor.

Table 2. SCF for Aluminum and Steel Alloy for different cut-outs.

Type of cut-out	Thickness of beam	Maximum stress σ_{max} N/mm^2		Stress concentration factor (K)	
		Aluminum	Steel	Aluminum	Steel
Circular	6	134.83	115.77	1.29	1.29
	8	255.53	219.42	1.28	1.28
	10	342.98	294.30	1.34	1.33
Square	6	376.97	312.17	1.81	1.75
	8	426.42	352.74	1.90	1.82
	10	461.90	381.79	1.97	1.88
Blunted square	6	354.49	305.3	1.69	1.69
	8	412.93	356.11	1.82	1.82
	10	433.35	374.20	1.83	1.83
Elliptical	6	248.19	213.21	1.47	1.47
	8	266.49	229.30	1.36	1.36
	10	314.35	269.90	1.48	1.48

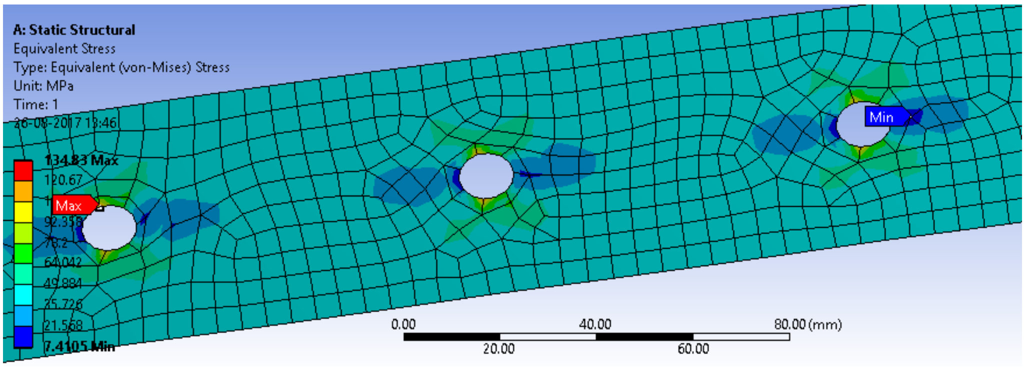
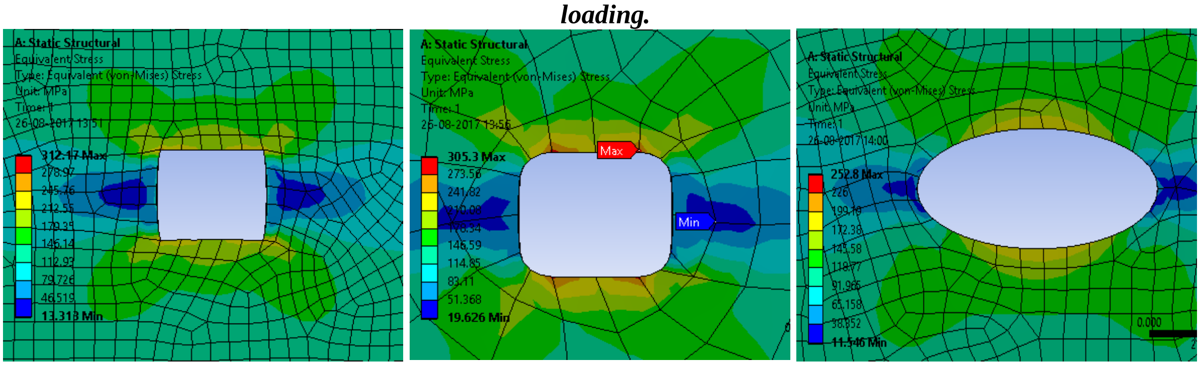


Figure 4. FEA Results for 6mm thick Aluminum beam having 3 series of circular cut-outs with tensile loading.



(a) *(b)* *(c)*

Figure 5. FEA results for 6mm thick Steel beam having 3 series of(a)square, (b)blunted square and (c)elliptical cut-outs with tensile loading

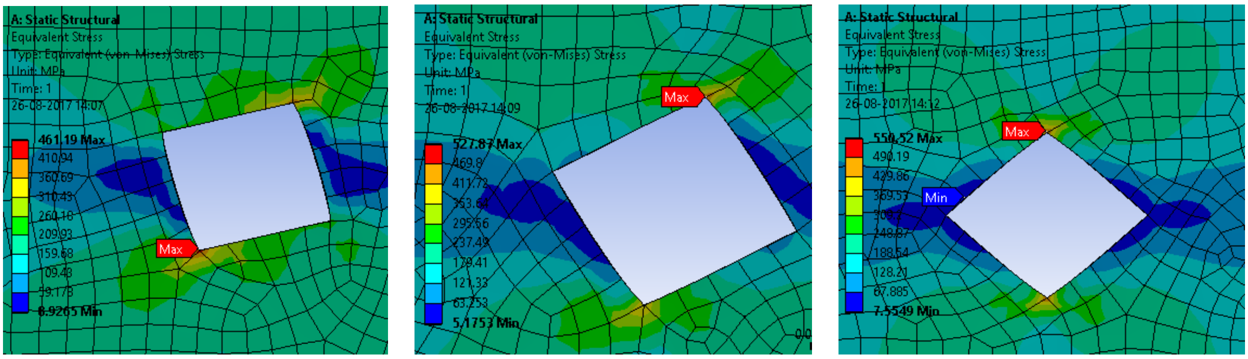
B. Beam having 3 series of square and triangular cut-outs with rotation

A beam (aluminum and steel) with fixed end support having spans 3m was loaded with calculated tensile load. 3 series of different shapes cut-outs were considered with rotation; square (with rotation at 15, 30 and 45) and triangular (with rotation at 0, 15 and 30), where dimensions of these cut-outs were considered as per given before.

Different thicknesses of beam like, 6mm, 8mm and 10mm were considered for analysis. The parameters of the beam studied were maximum principal stress, von misses stress, and stress concentration factor.

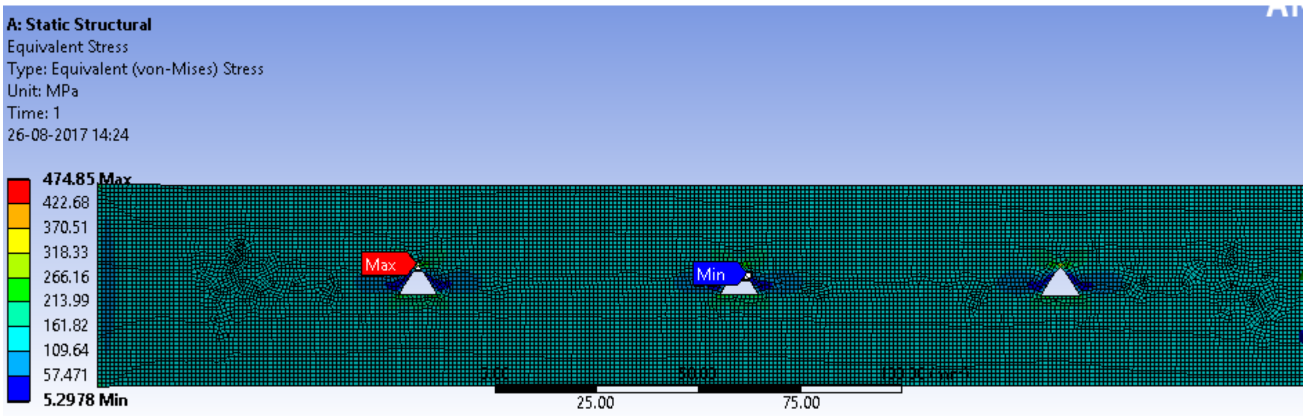
Table 3. SCF for Aluminum and Steel Alloy for different cut-outs with rotation

Type of cut-out	Thickness of beam	Rotation of cut-out	Maximum stress σ_{max} N/mm^2		Stress concentration factor (K)	
			Aluminum	**Steel**	**Aluminum**	**Steel**
Square	6	15°	405.86	350.77	1.93	1.93
		30°	493.38	428.00	2.22	2.24
		45°	523.42	453.20	2.08	2.08
	8	15°	461.19	398.86	2.02	2.03
		30°	527.87	458.29	2.19	2.21
		45°	550.12	447.79	2.02	2.03
	10	15°	481.08	416.06	2.02	2.02
		30°	549.17	478.64	2.18	2.20
		45°	580.08	498.36	2.03	2.03
Triangular	6	0°	474.85	413.55	2.00	2.02
		15°	445.07	387.15	1.93	1.95
		30°	451.80	391.82	1.66	1.67
	8	0°	516.98	450.23	1.94	1.96
		15°	535.15	465.69	2.07	2.09
		30°	-	-	-	-
	10	0°	545.96	475.80	1.93	1.95
		15°	551.86	474.44	2.01	1.99
		30°	-	-	-	-

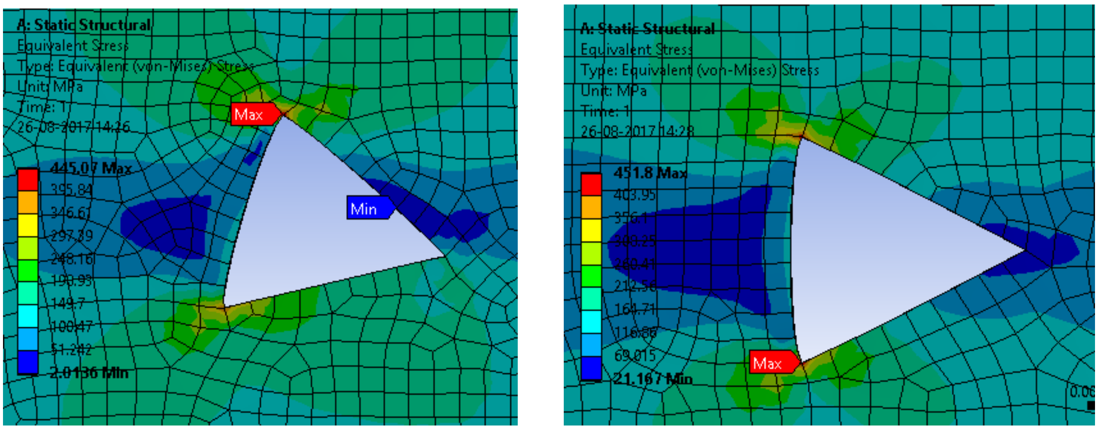


(a) (b) (c)

Figure 6. FEA results for 8mm thick Aluminum beam having 3 series of square cut-outs with rotation at (a)15°, (b)30° and (c)45° with tensile loading



(a)



(b) ***(c)***

Figure 7. FEA results for 6mm thick Aluminum beam having 3 series of triangular cut-outs with rotation at (a)0°, (b)15° and (c)30° with tensile loading

IV. CONCLUSION

For designing engineering structures with cut-out, a reliable estimation of SCF's is a must. This work proposed a simple computation method to estimate the SCF's for isotropic materials with a change in thickness of the material with different cut-outs.

- For all beam with cut-out Equivalent (VON-MISES) stress is predominant stress.
- There is no variation observed in theoretical values and finite element analysis results obtained by Ansys. Minimum difference between both results is 0.11% and maximum difference is 1.71%. Which is permissible.
- Stress Concentration can be reduced by providing more than one hole.
- It can be concluding that circular cut-outs are preferable from stress concentrations obtained by ANSYS.
- The bluntness of the corner radius has significant effect on stress concentration.
- The SCF's depend on the dimension ratio defined as the hole diameter of the beam to the width of beam, it is true for isotropic structure, variation in the actual structural dimensions are quite small.
- This project work reveals that the stress concentration factor is solely depending on the material.

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