Determination of Stress Concentration for Plate with Different Cut-Outs by Using Finite Element and Analytical Method

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Abstract: A study on mechanical engineering components with cutout, notches is very important, because there is a stress raiser/failure region area, where the stress is concentrating more and more. The elastic stress concentration is mainly depending on mode of loading, materials and geometry of the mechanical engineering components. The design engineers, academicians and researchers concentrated and focused on_fail safe design and safe life design. Plate is considered in both the cases is finite and infinite plate. A Plate is considered with different cutouts, such as circular and elliptical. The main objective of this study is to find out the stress concentration factor in plate with various cutout shapes. This concept is used in mechanical components/structures, for finding the elastic stress concentration. The methods compared are tabulated with their findings. Singularities of circular hole and elliptical hole in rectangular plate are considered in present study. Finite Element Method (FEM) used for fine mesh and MSC/NASTRAN V7 software used for extracting the results and results were validated by analytical or experimental method.

Key words: Finite plate, Infinite plate, cutouts, stress concentration

1. Introduction

The plates with cutouts are widely used in structural members. This cutout induces stress concentration in plate. A Plate is considered with various cutout shapes such as circular and elliptical. The main objective of this study is to find out the stress concentration in plate with various cutout shapes. For finding the stress concentration, a finite element program *MSC/NASTRAN V7* is used. In this work stress concentration depends on various parameters such as type of cutout shape, dimensions of plates and loading condition [1]. Few authors studied on stress concentration, focus on the structural members that are mostly subject to (or weakened by) stress concentration [2-4]. Among such studies, the work on stress concentration on cutouts include analytical works for the plates with various cutout shape [5], optimum design of holes and different cutouts by considering fatigue life [6].

The more important finding is that the stress concentration increases as the cutout become more oriented from baseline. This fact demonstrates that orientation is also relatively significant to control the stress concentration factor. The experimental photo-elastic test is carried out on Araldite model loaded in one direction for circular and elliptical cutout shape. The analytical results are compared with Finite Element Analysis results (FEA) [8]. By comparing the results, it is found that the stress concentration factor by experimentation and by FEA is in good agreement. Localized stress around geometric discontinuities such as holes, shoulders, and grooves cannot be predicted accurately using strength of material (SOM) approach. The Stress concentration factors often determined experimentally or computationally, are used to scale the nominal stress in a continuous structure to account for the effect of the discontinuity. Stress analysis of thick flat plate with various cutout shapes subjected to axial tension has been carried out using the finite element method (FEM).

2. Stress Concentration Factor (SCF)

It is convenient to express stresses in non-dimensional form. However, there is usually more than one reference stress which may be used for this purpose and the resulting stress-concentration factors (*SCF*) may be seen to have merit for particular purposes. Since more than one definition is used here, the matter will be considered before the results are presented [9].

$$SCF = \frac{Maximum\ Stress\ at\ cut\ out}{Normal\ Stress\ Based\ on\ Gross\ Cross-section}$$

3. Objectives

- To study the stress concentration factor in finite and infinite plate with various cutout shapes such as circular and elliptical.
- Comparing the value of stress concentration factor obtained by FEA to experimental /analytical methods.
- To utilize the above findings for better safe design of components

4. Methodology

- In this study CATIA V5 is used for creating 3dimensional models.
- Finite Element Method is used for fine meshing the 3D models by considering aspect ratio <5 (Component safe).
- MSC/PATRAN is used for extracting the results of meshed models and comparing the obtained results with analytical solution.

5. Materials used

Table: 5.1 Material properties details

Name of the Material	Young's modulus (Gpa)	Yield strength (Mpa)	Poisons ratio
Alluminium 2014	72	290	0.33
Titanium (Ti-5% Al-2.5%)	110	795	0.34
Nickel(5Ni steel)	207	530	0.31
Steel 0.2%C	200	250	0.30

6. Plate dimension (isotropic plates)

6.1. Finite plate details:

1) Length of plate………………..400 mm
2) Width of plate………………...100 mm
3) Thickness of plate……….5, 7,9,11 and 13mm.

6.2. In-finite plate details:

Condition for selecting in-finite plate W/d ≥ 10

1) Length of plate………………..500 mm
2) Width of plate………………...100 mm
3) Thickness of plate………5, 7, 9,11and 13 mm.

6.3. Cut-out dimension:

1) Circular cut-out………………….10 mm Diameter
2) Elliptical cut-out………………..10 mm major and 5 mm minor axis

6.4 Model converged

It is useful to convert from coarser mesh to fine mesh. In each and every iteration number of elements will increases gradually, due to increasing in the number of elements, size of the element will decreases and stress concentration will increases gradually, at certain level it will be constant as shown in the Fig. 6.1. In this process, iterations have got same answer as shown in Table 6.1. By these five iterations we can select the accurate maximum stress.

Table: 6.1 Details of convergence criteria.

No. of iterations	Aspect ratio	No. of elements	Maximum stress
1	5	3690	237
2	4.5	4180	228
3	4	4306	232
4	3.5	4908	232
5	3	5323	232

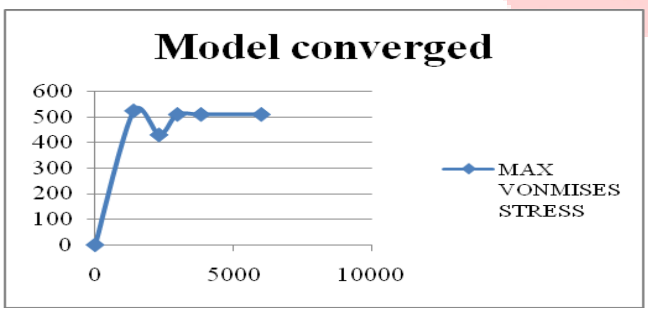

Fig. 6.1 Graph shows that Number of elements V/s Max. Von-misses stress.

7. Results and discussions

1. Circular cutout

The below Tables 7.1 to 7.4 shows the SCF by FEM and analytical results for the Al-2014, nickel, Ti and steel plates with circular cutouts with different thicknesses. As a result, we can see that many differences occur in the maximum stresses and SCF by FEM and analytical method.

Table: 7.1 Circular cut-out (Aluminum 2014)

Sl. No.	Thickness (t) mm	FEM result (SCF)	Analytical results (SCF)	Max. Stress (FEM)	Max. stress (analytical)
1	5	2.7	2.72	490	492.53
2	7	2.5	2.72	486	518
3	9	2.3	2.72	454	533
4	11	2.2	2.72	440	544
5	13	2.15	2.72	448	548

Table: 7.2 Circular cut-out (Nickel)

Sl. No.	Thickness (t) mm	FEM result (SCF)	Analytical result (SCF)	Max. stress (FEM)	Max. stress (analytical)
1	5	2.7	2.72	893	900
2	7	2.5	2.72	884	948
3	9	2.3	2.72	832	974
4	11	2.2	2.72	825	991
5	13	2.15	2.72	820	1003

Table: 7.3 Circular cut-out (Ti-5% AL2.5%)

Sl. No.	Thickness (t) mm	FEM result (SCF)	Analytical result (SCF)	Max. stress (FEM)	Max. Stress (analytical)
1	5	2.7	2.7	1350	1340
2	7	2.5	2.7	1330	1411
3	9	2.3	2.7	1250	1451
4	11	2.2	2.7	1250	1476
5	13	2.15	2.7	1230	1493

Table: 7.4 Circular cut-out (steel)

Sl. No.	Thickness (t) mm	FEM result (SCF)	Analytical results (SCF)	Max. Stress (FEM)	Max. stress (analytical)
1	5	2.6	2.7	420	421

2	7	2.5	2.7	410	443
3	9	2.3	2.7	392	456
4	11	2.2	2.7	389	464
5	13	2.15	2.7	387	469

2014

2. Elliptical cutout

The below Tables 7.5 to 7.8 shows the SCF by FEM and analytical results for the Al-2014, nickel, Ti and steel plates with elliptical cutout with different thicknesses. As a result, we can see that many differences occur in the maximum stresses and SCF by FEM and analytical method.

Table:7.5 Elliptical Cut-Aluminum

Sl. No.	Thickness (t) mm	FEM result (SCF)	Analytical results (SCF)	Max. Stress (FEM)	Max. stress (analytical)
1	5	2.5	2	378	294
2	7	2.25	2	375	333
3	9	2.09	2	372	354
4	11	1.98	2	364	368
5	13	1.7	2	328	376

Table: 7.6 Elliptical cut-out (nickel)

Sl. No.	Thickness (t) mm	FEM result (SCF)	Analytical results (SCF)	Max. Stress (FEM)	Max. stress (analytical)
1	5	2.5	2	673	538
2	7	2.24	2	685	610
3	9	2.09	2	680	648
4	11	1.98	2	666	672
5	13	1.7	2	601	690

Table: 7.7 Elliptical cut-out (Ti-5% AL2.5%)

Sl. No.	Thickness (t) mm	FEM result (SCF)	Analytical results (SCF)	Max. Stress (FEM)	Max. stress (analytical)
1	5	2.5	2	1004	806
2	7	2.2	2	1003	913
3	9	2.09	2	1002	972
4	11	1.98	2	1001	1009
5	13	1.7	2	899	1035

Table: 7.8 Elliptical cut-out (steel)

Sl. No.	Thickness (t) mm	FEM result (SCF)	Analytical results (SCF)	Max. stress (FEM)	Max. stress (analytical)
1	5	2.5	2	325	254
2	7	2.24	2	323	289
3	9	2.09	2	320	305
4	11	2	2	319	317
5	13	1.7	2	284	325

In addition, we can see that the thickness increases the stress concentration factor (SCF) decreases in all the cases as shown in Fig. 7.1. The Fig. shows the comparison between circular and elliptical cutout shapes.

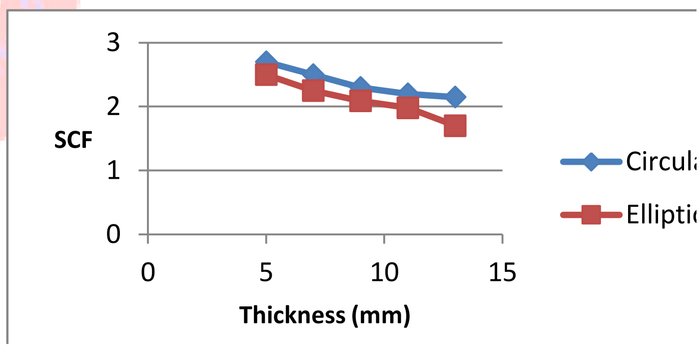

Fig. 7.1 Graph shows that thickness V/s SCF.

8. Conclusion

For designing engineering structures with various cutouts shape, a reliable estimation of stress concentration factor is must. This work proposed a simple computation method to estimate the stress concentration factor in plate with circular and elliptical cutout shape subjected to uniform tensile loading condition.

i. The proposed computation method is simple efficient and is verified by FEM simulation
ii. Stress concentration depends upon shape of cutout, plate dimensions and type of loading.
iii. From the analytical and FEA results it is concluded that the stress concentration for elliptical cutout is less than circular cutout, and withstand more load, thus component is safe.
iv. It is concluded that the thickness of plate increases the stress concentration and the maximum stress (FEM) decreases.
v. Finally concluded that the elliptical cutout well suited for designing engineering structures.

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