Relief holes for the mitigation of stress concentration factor of a thin rectangular plate under in-plane loading

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ABSTRACT

Abstract: Plates with different discontinuities are widely used in many fields of engineering. The presence such a discontinuities create stress concentration which reduces the mechanical strength of the structure. Mitigation of stress can be obtained by area reduction method which can be achieved by introducing relief holes around main hole or notch. The study of stress concentration factor(SCF) for the rectangular plate with central circular hole under in plane load is analyzed with the help of finite element method.SCF was mitigated by introducing auxiliary circular hole around main circular hole. The finite element formulation is carried out by using the software HYPERMESH.

Keyword: - *Main hole, stress concentration factor, auxiliary holes, hyper mesh, Mitigation of stress concentration factor*

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1. INTRODUCTION

Any discontinuity in the structure penetrates the strength of the structure .An applied external force causes inner forces in the carrying structure. Inner forces are distributed differently in each part of structure. When inner forces go around holes or notches they will concentrate near such obstacle. These make the structure weak and susceptible to failure. Therefore it is necessary to investigate the state of stress around the holes for safety and proper design of such structures. Efforts are being made to reduce this stress concentration effect. Several methodologies can be available for solution of such problem and these can be divided into three general categories: Experimental, analytical and numerical methods. Although experimental methods give most reliable results they are very expensive as they require various special equipments, testing facilities etc. Analytical solution of every problem is almost impossible because of complex boundary conditions and shapes. Therefore numerical methods are popular by researchers in last few decades. In this paper an analysis of rectangular isotropic plate with central circular hole has been carried out to study the effect of size of discontinuity on SCF. The reduction in SCF is achieved by introducing one set of auxiliary hole on both side of main hole.

2. METHODOLOGY

Topology Optimization is a mathematical technique that produces an optimized shape and material distribution for a structure within a given package space. By discretizing the domain into a finite element mesh, OptiStruct calculates material properties for each element. The OptiStruct algorithm alters the material distribution to optimize the user-defined objective under given constraints. Convergence occurs in line with the description provided on the Iterative Solution page. OptiStruct solves topological optimization problems using either the homogenization or density method. Under topology optimization, the material density of each element should take a value of either 0 or 1, defining the element as being either void or solid, respectively. Unfortunately, optimization of a large number of discrete variables is computationally prohibitive. Therefore, representation of the material distribution problem in terms of continuous variables has to be used.

3. PROBLEM DEFINITION

The objective of this project is to provide structural engineers a simple and reliable estimation method for SCFs and its mitigation in common structures. The proposed method is to study a plate of dimension 200mm X 100mm X 1mm with a circular hole at centre under uniform distributed static loading of σ N/m2 by finite element method. The analysis is carried out for six D/A ratio on plates of specific material.

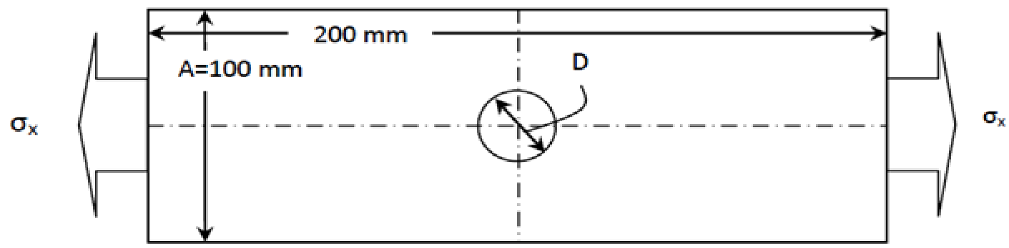


Fig -1: Model of plate with centre circular hole under in plane loading

4. FE MODEL SETUP

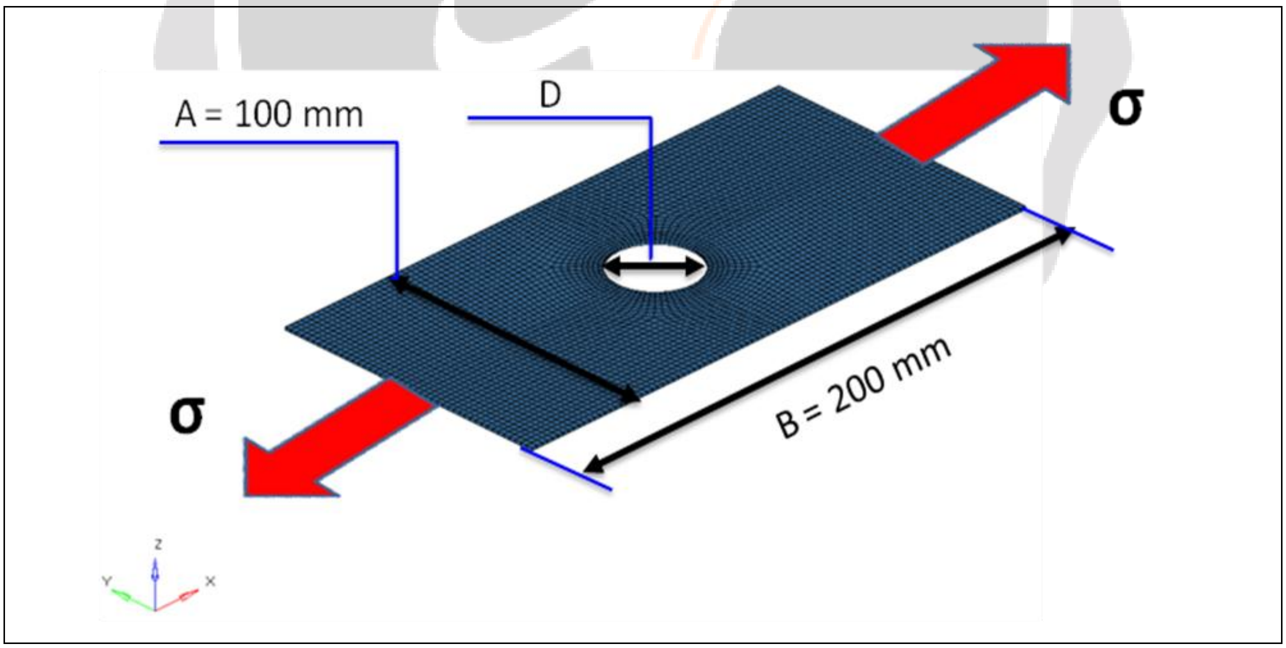


Fig -2: FE model setup

-The FE Model consists of a rectangular plate of size 200 x 100 mm having a hole of diameter 'D'.
-Hexahedral mesh with average size 3mm and minimum size 0.23 mm with hole at center with multilayer washer is used to model rectangular plate with hole as shown below.
-Three layers of mesh are modeled across thickness with circular rings of elements around hole.

-Total number of elements (D/A =0. 1) in mesh are 21060 and total number of nodes are 28684.
-Constant and equal pressure is applied at both ends of plate along the edges which produces stress ‘σ’.
-The test is carried out for various D/A ratios.
-Various output of from test like σx, σy, σxy, Δx, Δy, Δxy are recorded and analyzed.

5. UNITS

	(a)	(b)	(c)
Length unit	meter	millimeter	millimeter
Time unit	second	second	millisecond
Mass unit	kilogram	tonne	kilogram
Force unit	Newton	Newton	kiloNewton
Young’s Modulus of Steel	210.0E+09	210.0E+03	210.0
Density of Steel	7.85E+03	7.85E–09	7.85E–06
Yield stress of Mild Steel	200.0E+06	200.0	0.200
Acceleration due to gravity	9.81	9.81E+03	9.81E-03
Velocity equivalent to 30 mph	13.4	13.4E+03	13.4

Fig -3: FE model unit system

6. STATIC ANALYSIS RESULTS

Table -1: Compiled result summary

Applied stress= 6 MPa								
D/A	**σx**	**σy**	**σxy**	**σvon**	**Defx**	**Defy**	**Defz**	**Defxy**
0.1	16.18	2.405	4.081	15.86	2.567	0.383	0.01414	2.659
0.2	17.45	2.714	4.562	17.21	2.655	0.4961	0.01474	2.777
0.3	18.75	2.789	4.792	18.50	2.833	0.7087	0.01853	2.915
0.4	21.16	2.961	5.274	20.95	3.145	1.061	0.02065	3.276
0.5	24.76	3.014	5.771	24.55	3.67	1.666	0.02621	3.761
0.6	30.38	3.135	6.342	30.16	4.436	2.687	0.03228	4.598
No hole	6	1.10E-11	2.80E-12	6	2.544	0.3708	0.01142	2.621

6.1 SCF values

Table -2: SCF values

D/A	**SCF**
0.1	2.64
0.2	2.86
0.3	3.08
0.4	3.49
0.5	4.09
0.6	5.02
No hole	1

6.2 SCF graph

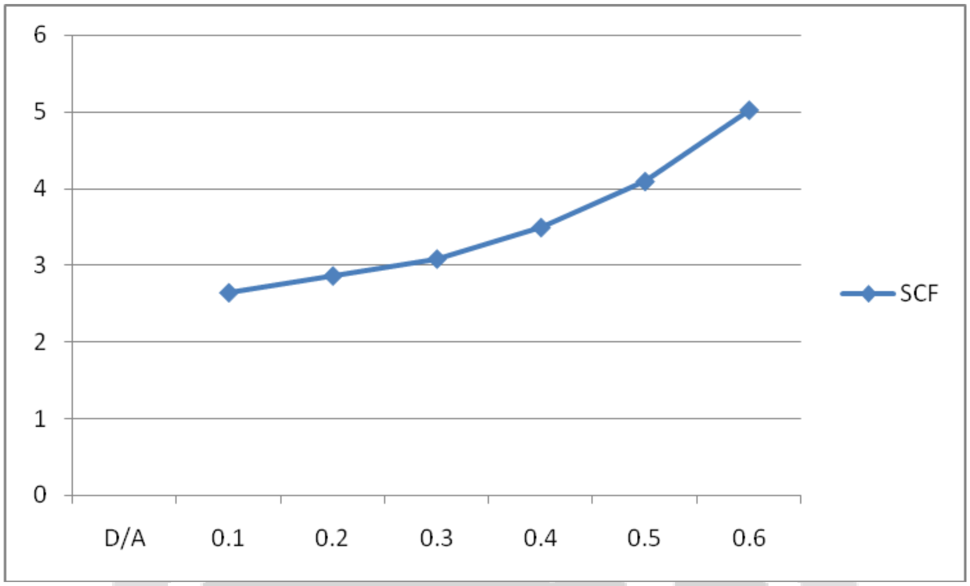


Chart -1: SCF vs. D/A graph

7. OPTIMIZATION

Optimization can be defined as the automatic process to make a system or component as good as possible based on an objective function and subject to certain design constraints. There are many different methods or algorithms that can be used to optimize a structure, an OptiStruct is implemented some algorithms based on Gradient Method.

7.1 Topology optimization

Topology Optimization is a mathematical technique that produces an optimized shape and material distribution for a structure within a given package space. By discretizing the domain into a finite element mesh, OptiStruct calculates material properties for each element. The OptiStruct algorithm alters the material distribution to optimize the user-defined objective under given constraints.

7.2 set up

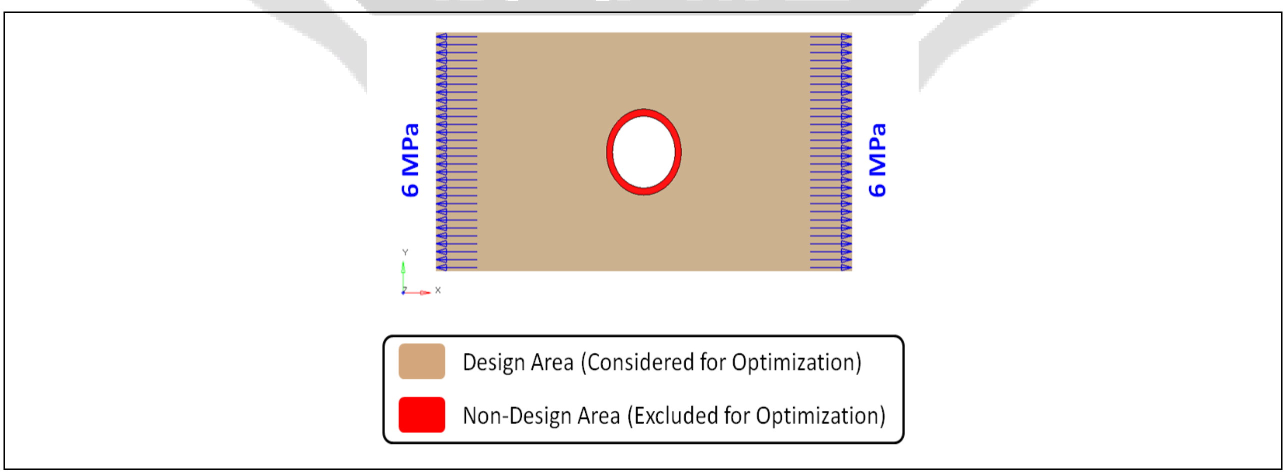


Fig -4: Topology optimization set up

The load set-up is similar to previous study. A rectangular plate of 200 x 100 mm dimension with hole at center with D/A=0.4 is applied stress / pressure at edges of 6MPa. Further Optimization loadcase is defined to get directions for mitigation of stress.

7.3 optimization procedure

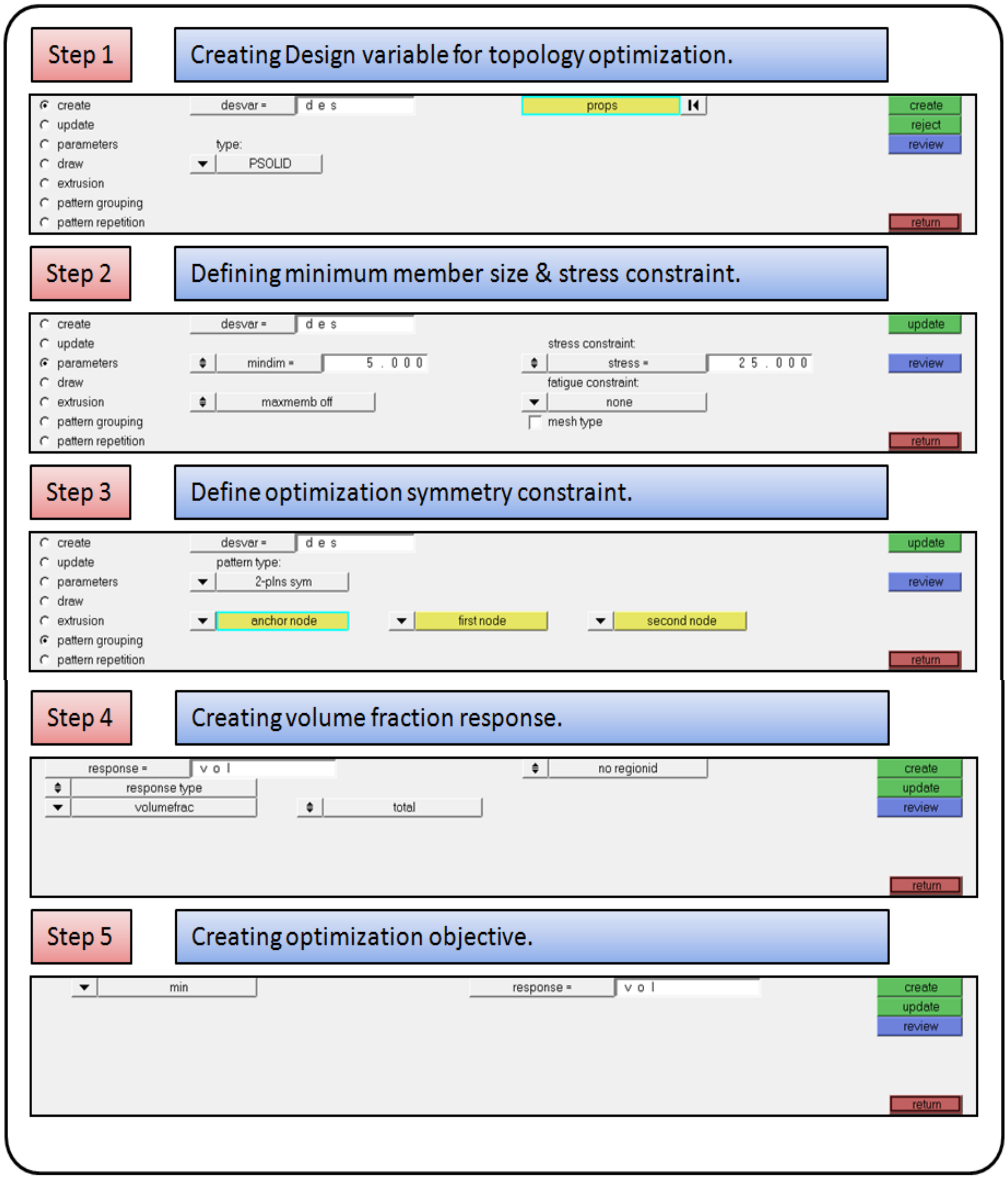


Fig -5: Optimization procedure

7.4 Optimization solution

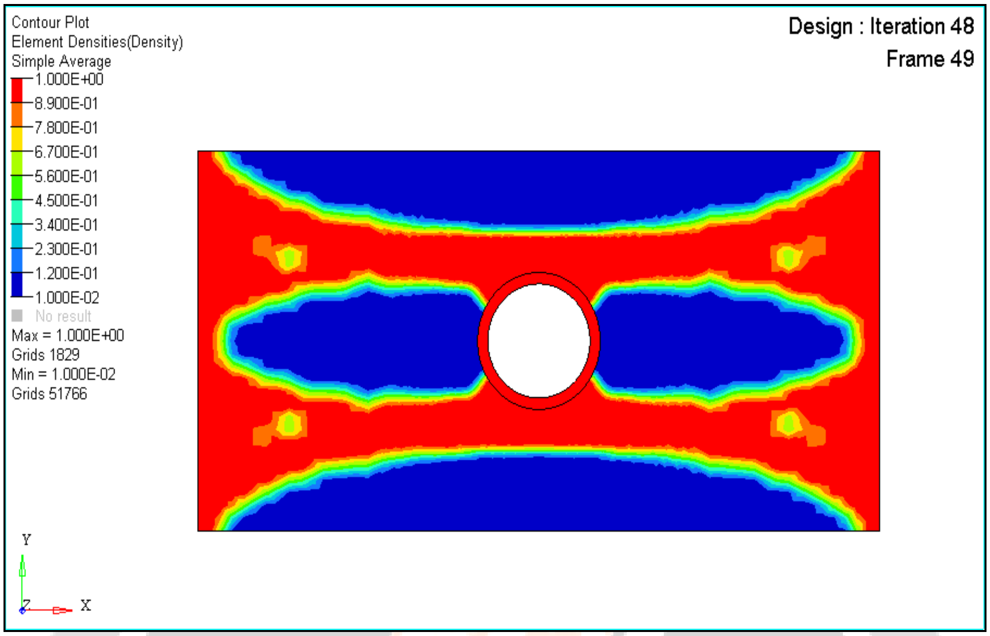
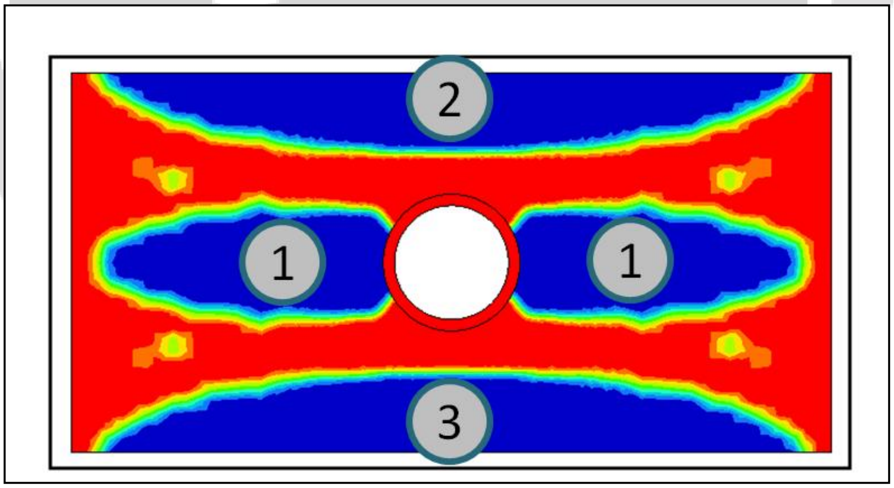


Fig -5: Optimization solution

- After iterating 48 times the optimization solution has converged with feasible design.
- The optimization solution shows three major areas for topology optimization as seen below.



- The solution shows blue region where material density can go upto 0% whereas red region indicates material density need to be 100%
- The regions 1, 2 & 3 indicates areas permissible for placement of relief holes.
- Regions 2 & 3 is excluded for placement of relief hole as they do not come in load path and are also near boundary which actually violates rectangular shape of plate.
- Hence it is concluded that region 1 which is elliptical in shape must accommodate relief holes within its boundary.

7.5 Optimization results with one set of auxiliary hole

Table -3: Results with one set of auxiliary holes

Von Mises Stress Comparision

Distance from main hole (mm)	D/A	0.1	% Improvement	0.2	% Improvement	0.3	% Improvement	0.4	% Improvement	0.5	% Improvement	0.6	% Improvement
	10	13.13	17.21%	14.57	15.34%	16	13.51%	18.37	12.32%	22.02	10.31%	26.54	12.00%
	20	13.74	13.37%	15.07	12.43%	16.56	10.49%	18.99	9.36%	22.28	9.25%	27.01	10.44%
	30	13.82	12.86%	15.4	10.52%	17.12	7.46%	19.61	6.40%	22.79	7.17%	32.07	-6.33%
	40	13.82	12.86%	15.98	7.15%	17.56	5.08%	20.1	4.06%	25.26	-2.89%	29.22	3.12%
Original Values		15.86		17.21		18.5		20.95		24.55		30.16	

8. FINAL TRIAL

From The graph of SCF vs. D/A ratio it is observed that as D/A ratio increases SCF also increases. Lower values of SCF are obtained when auxiliary holes are placed at a distance of 10mm from the main hole. The lowest value of SCF is obtained for D/A ratio 0.1.Similar trend of change in SCF is observed with D/A ratio. We can further reduce the distance between main hole and auxiliary hole and take a trial for 5mm distance. The results obtained are as following.

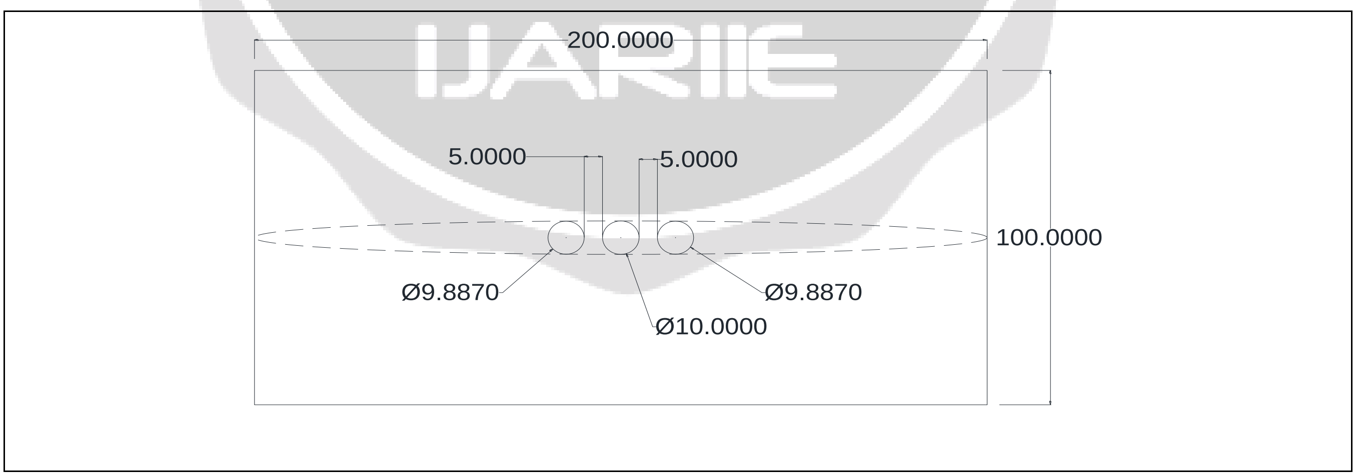


Fig -6: D/A=0.1 and auxiliary holes are at a distance of 5mm from main hole

8.1 Results of final trial

Table -4: Results of final trial

Applied stress = 6MPa				
D/A	**σx**	**σy**	**σz**	**σvon**
0.1	11.58	1.53	0.415	11.14

9. RESULTS AND DISUSSIONS

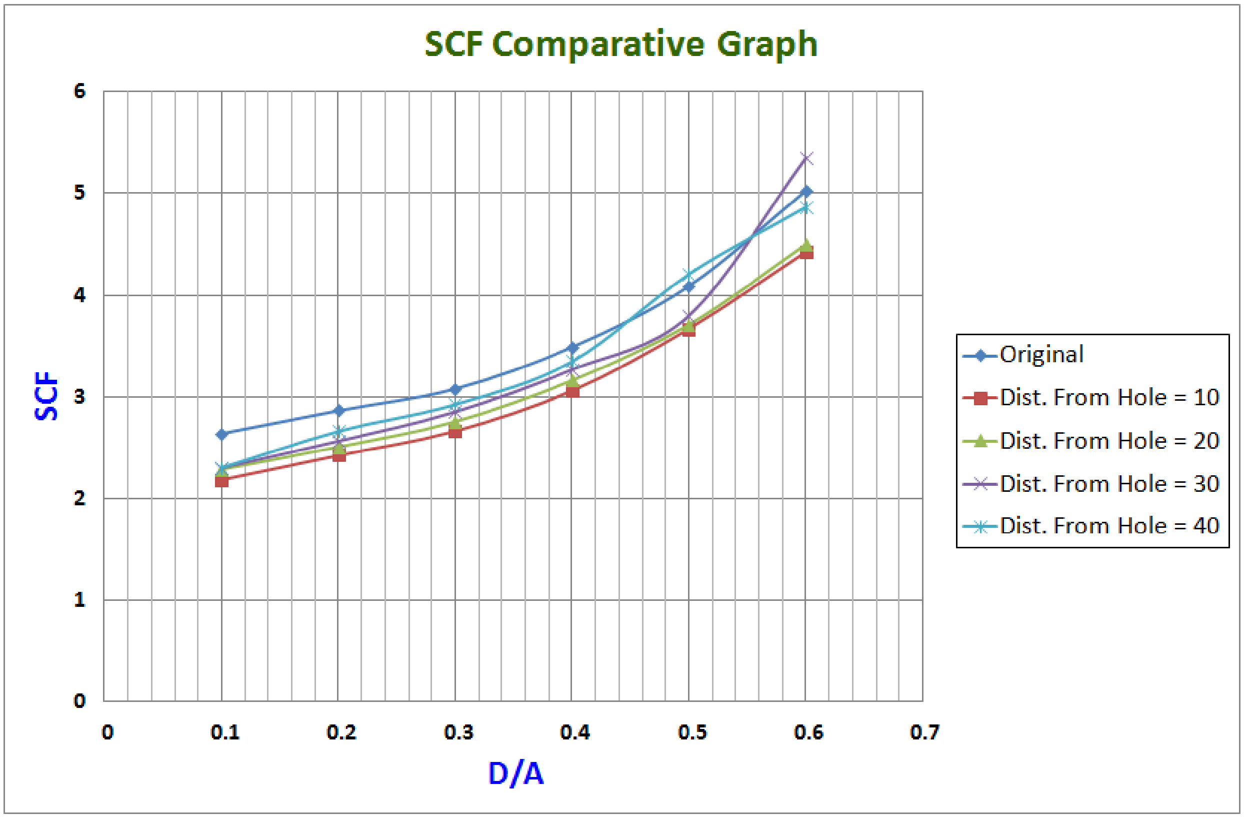


Chart -2: Stress Concentration Factor vs. D/A graph

From the analysis it is observed that SCF follows a symmetric trend with all D/A ratio. SCf is sensitive to D/A ratio and geometry of the plate with holes. When auxiliary holes are placed at a distance of 10 mm then for D/A =0.1 the value of SCF is 2.18.silarally for D/A=0.2 the value of SCF reported is 2.57.For D/A ratio 0.3, 0.4, 0.5, 0.6 the values of SCF obtained are 2.66,3.06,3.67,4.42 respectively. Higher values of SCF are obtained for higher D/A ratio. The values of SCF go on increasing when auxiliary holes are placed at a distance away from the main hole.

10. CONCLUSIONS

The maximum stress concentration is always occurred on hole boundary in a finite width plate with central circular hole under in plane static loading.SCF increases as D/A ratio increases. Plate with D/A ratio 0.1 shows better result with one set of auxiliary hole when it is kept at a distance 5mm from the main hole. The maximum mitigation in SCF is reported as 30%.

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