Analysis and Comparison of Stress concentration Factor in Notched Sheet Using ANSYS Software

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Abstract- *When a plate is subjected to tensile force on both the sides, stress distribution will take place evenly throughout the cross-sectional area of the plate. If there exists any discontinuity in the cross section of the plate, stress concentration will take place at that particular region. The ratioof maximum stress, thus developed, and the nominal stress gives the stress concentration factor.*

This stress concentration in a plate with a hole was studied using Finite Element Method. Different dimensions and areas of the hole were taken into consideration and the results were compared.

The effect of tensile load on a plate with discontinuity in cross-sectional area was studied using Finite Element Analysis and Method. The study incorporates 3 types of discontinuities in cross-section in the plate:

1. *A hole in the center of the plate*
2. *A plate with double U-notches*
3. *A plate with single U-notch.*

Keywords- stress concentration; discontinuity; stress analysis; Finite Element Analysis; notches; cross-sectional uniformity; tensile force; design failure; principal stress; 2-D analysis.

I. INTRODUCTION

Stress concentration is the basic cause of failure in any component. It can be defined as the stress gradient that gets accumulated at a particular localized area where there is a change in uniformity of the cross-section of the component.[1] Stress concentration, for example, can occur in a plate where a hole is drilled or a notch that occurs due to any human or mechanical error. The stress gets concentrated at this particular region, giving rise to stress-concentration factor. This stress concentration increases with the load applied and gradually leads to failure of the plate.

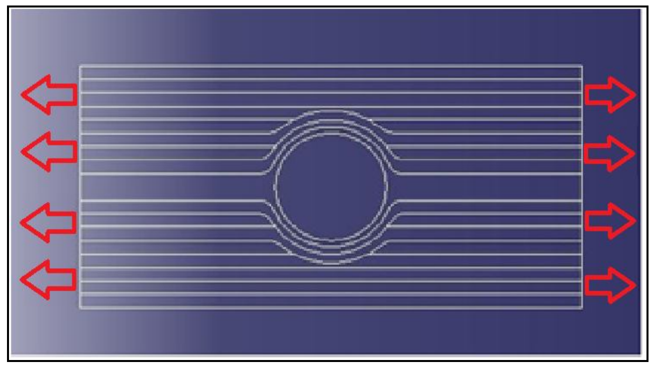

Figure 1 Representative Illustration of Stress Concentration

Stress concentration is a result of two factors:

1) Variation in geometrical and material properties, and
2) Contact forces.

All the three cases were studied using ANSYS R16.2 and the results were noted.

1. PLATE WITH HOLE

The plate demonstrated in fig. 1 was subjected to tensile load which, as a result, induced stress in the vicinity of the hole. The material of the plate used for analysis was structural steel and the dimensions are as under:

Length, l	= 192 mm
Width, w	= 80 mm
Thickness, t	= 5 mm
Diameter of the hole, d	= 48 mm.

The modeling and analysis of the plate was carried in ANSYS R16.2.

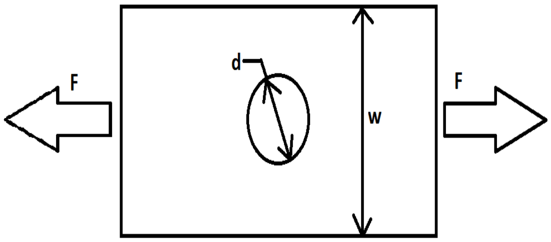

Figure 2: Central Circular Hole In a Member of Rectangular Cross Section

Considering the mechanical properties of structural steel, it can be saidthat the tangential stress and shear throughout the plate will be *zero* as the stress induced is principal stress.

The nominal stress in the plate can be obtained by ratio of the force applied to the cross-sectional area at the discontinuity. Hence, it can be given by:

$$\sigma = \frac{F}{A} = \frac{F}{(w-d)t} \ldots \textbf{Eq. (1)}$$

This nominal stress when multiplied with the stress-concentration factor provides the maximum stress produced in the plate[3]:

$$\sigma_{max} = \sigma * K_t \cdots \textbf{Eq. (2)}$$

The stress-concentration factor for this particular case is given by[1]:

$$K_t = 3 - 3.13\left(\frac{d}{w}\right) + 3.66\left(\frac{d}{w}\right)^2 - 1.53\left(\frac{d}{w}\right)^3 \cdots \textbf{Eq. (3)}$$

Where, d = diameter of the hole,
w = width of the plate.

Table 1: Central Circular Hole in a Member of Rectangular Cross Section

d	w	d/w	K_t
8	80	0.1	2.72
16	80	0.2	2.50
24	80	0.3	2.34
32	80	0.4	2.23

Simulation was carried out by applying tensile force of 20 KN on the pair of vertical sides and the results obtained were noted. The distribution of stress along the entire plate is shown below. The maximum stress occurred at the region around the hole which is shaded in red.

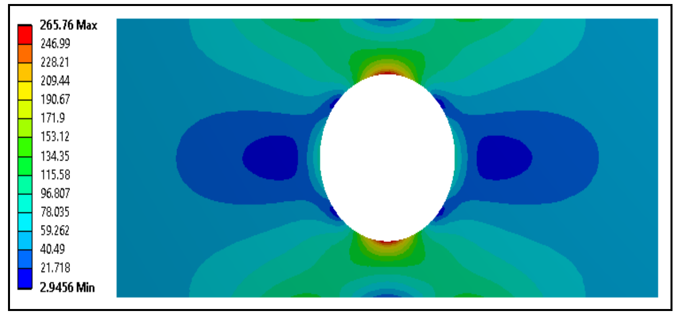

Figure 3: Stress distribution for a plate, with Centered HOLE, in tension

The stress in the plate gradually increased from the edge towards the hole and became maximum on its circumference. This can be visualized by studying the graph plotted that shows that the nodes nearest to the discontinuity in plate facedmaximum stress than those that were located comparatively further:

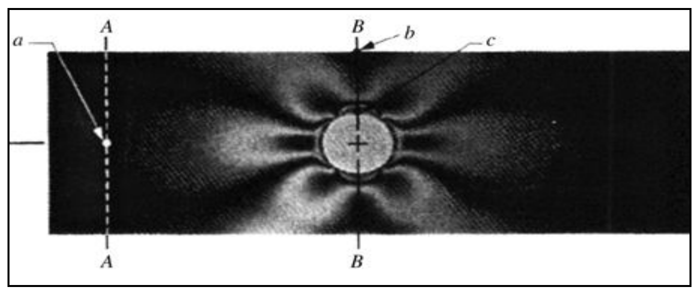

Figure 4: PHOTO-ELASTIC MODEL OF STRESS CONCENTRATION IN PLATE WITH HOLE[1]

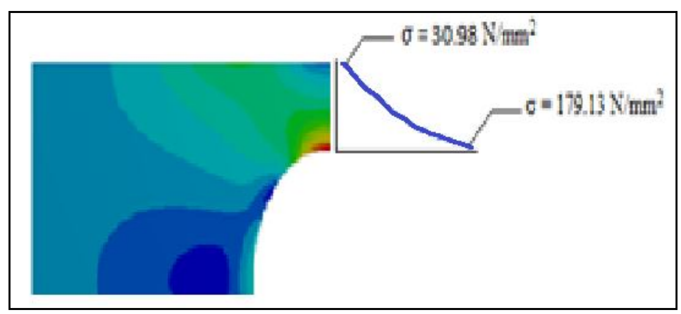

Figure 5: GRAPH SHOWING THE INCREASE STRESS TOWARDS THE HOLE

While carrying out simulation, it is to be noted that the mesh generated must be of good quality. Hence, to obtain accurate results, the mesh generated throughout the face of the plate must be of proper quality. If not, then at least the region around the hole must have best quality elements in the mesh as it is the area of concern in this case.

2. DOUBLE U -NOTHES IN A PLATE WITH RECTANGULAR CROSS-SECTION

In the previous analysis, the stress concentration took place at the hole. However, that is not the only case of deformity in a plate. Notches also cause distortion in the stress lines throughout the plate. It is the height and radius of the notch that decide the maximum stress occurring at that region.

Another analysis was done of a plate with two U-notches that were opposite to each other, having radius r and height h.

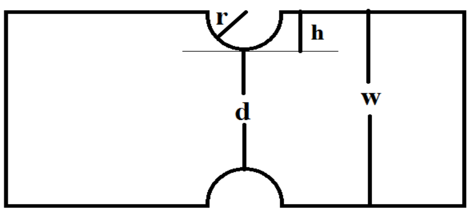

Figure 6: TWO U -NOTHES IN A MEMBER OF RECTANGULAR SECTION

Here, h/r is the ratio that played a significant role. The stress-concentration factor differed drastically with a small change in the ratio. In the analysis, the h/r ratio was taken as 1.33. In a plate with two U-notches, $K_t$is calculated by[1]:

$$K_t = C_1 + C_2\left(\frac{2h}{w}\right) + C_3\left(\frac{2h}{w}\right)^2 + C_4\left(\frac{2h}{w}\right)^3 \quad \text{...Eq. (4)}$$

Where, C_1, C_2, C_3, C_4 are constants that depend on h/r. Different values of K_t were obtained while keeping the ratio h/r same. The values obtained areshown below:

Table 2: TWO U-NOTCHES IN A MEMBER OF RECTANGULAR SECTION

h	r	h/r	w	h/w	K_t
10	7.50	1.33	80	0.12	2.52
20	15	1.33	80	0.25	1.79
25	18.75	1.33	80	0.31	1.48
30	22.50	1.33	80	0.37	1.24

In analysis, the dimensions taken were:

h = 20 mm; r = 15 mm; w = 80 mm. A tensile force of 20 KN was applied on the two vertical sides of the plate. The nominal stress and the maximum stress obtained to the corresponding data are 100 N/mm^2 and 179.13N/mm^2.

The analysis of the plate with double U-notches is shown below:

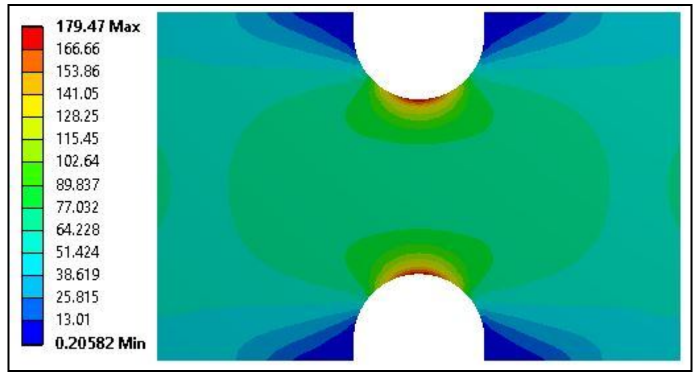

Figure 7: Stress distribution for a plate with double notches in tension

It can be visualized that maximum stress occurred at the highest point of the notch. The stress decreased gradually in the elements away from the notch. The distribution of stress throughout the plate is shown in the graph:

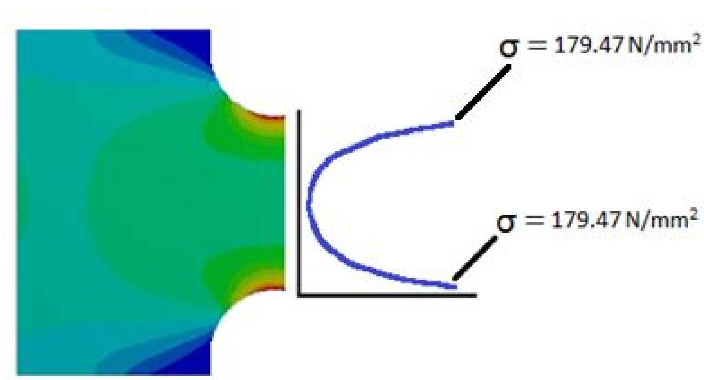

Figure 8: GRAPH DEMONSTRATING THE INCREASE STRESS TOWARDS THE NOTCHES

3. SINGLE U-NOTCH IN A PLATE WITH RECTANGULAR CROSS-SECTION

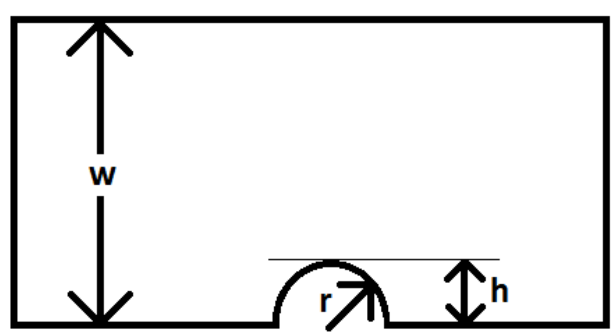

Figure 9: Single U-Notch In A Member Of Rectangular C/S

Such plate has only single region where there is a variation in cross-section in the form of a notch. Like other cases, this analysis was also performed by subjecting the vertical sides of the plate to tensile force of 20 KN.

Table 3: ONE U- NOTCH IN A MEMBER OF RECTANGULAR C/S

h	r	h/r	w	h/w	K_t
10	4	2.5	80	0.12	3.05
20	8	2.5	80	0.25	2.28
25	10	2.5	80	0.31	2.00
30	12	2.5	80	0.37	1.79

The stress concentration factor in this case is given by[1]:

$$K_t = C_1 - C_2\left(\frac{2r}{w}\right) + C_3\left(\frac{2r}{w}\right)^2 - C_4\left(\frac{2r}{w}\right)^3 \quad \text{...Eq.(4)}$$

Where, C_1, C_2, C_3, C_4 are constants that depend on h/r. Here, the dimensions taken into consideration while performing analysis were:

h = 20 mm; r = 8 mm; w = 80 mm. The nominal stress obtained was 66.67 N/mm^2 and maximum stress obtained was 152.31 N/mm^2.

The picture demonstrating the stress concentration in different regions of the plate is shown as follows:

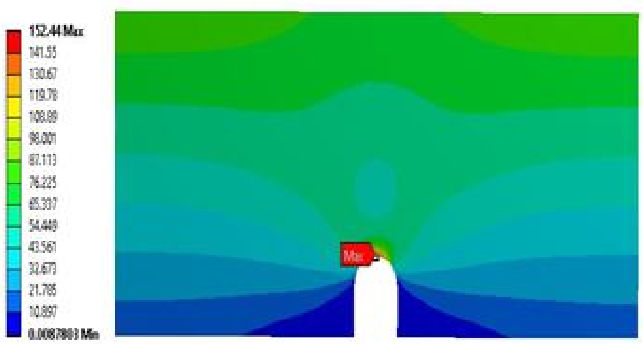

Figure 10: Stress distribution for a plate with SINGLE notch in tension

As it is the property of stress-concentration, like in other cases, the elements nearest to the discontinuity or the notch experienced maximum stress. The variation in stress along the plate is shown as follows:

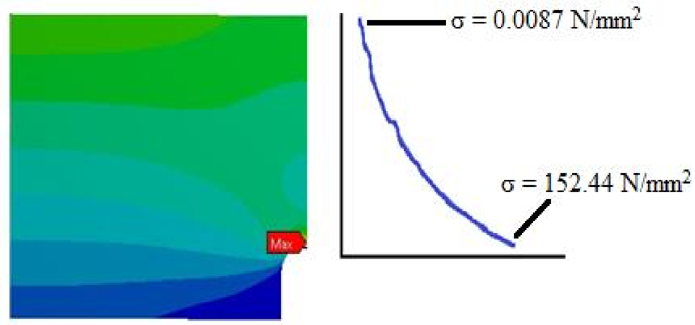

Figure 11: Graph Demonstrating The Increase Stress Towards The Notches

II. CONCLUSION

By this, it can be concluded that if the diameter of hole or notch increases provided that the width of the plate is constant, then the stress concentration factor gradually decreases in the elements as they proceed nearer to the deformity. However, the stress goes on increasing in those elements located in the vicinity of the notch or the hole and maximum stress is generated in the element located on the deformity where the force line is tangential.

It can also be concluded that a hole, no matter how small, in a pressure vessel or a component under loading conditions can cause stress concentration in that region of hole and can lead to complete failure of the system.

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