# Analysis of the stress concentration on cut-out orientation in plates

[1] S.B.Masuti, [2] K.S.Mangrulkar,

[1]Lecturer in Mechanical Engineering Department, [2]Professor in Mechanical Engineering Department
[1]SVSMD's KKI Polytechnic, Akkalkot, India
[2]N.B.Navale Sinhgad College of engineering, Solapur, India
Email – [1]masutisangam@gmail.com [2]ksmangrulkar.nbnscoe@gmail.com

***Abstract:*** *Openings/cut-outs are made into structures in order to satisfy some service requirements, results in strength degradation. In practice different shape of holes are used for different applications for an example manhole of any pressure vessel is either circular or elliptical while the window or door of an airplane is rectangular hole having chamfer of some radius at corners.*

*This hole/opening works as stress raisers and may lead to the failure of the structure/machine component. Hence it is an important aspect of stress analysis to predict stress concentration for regular or irregular holes. The irregularity in the hole shape may be because of chemical degradation. Under the effect of external loading and chemical process some irregular shapes may evolved. It is necessary to know stress distribution around such irregular shaped hole which may be useful to know hole shape evolution.*

***Key Words:*** *SCF, Radius ratio, Orientation of cut-outs*

## 1. INTRODUCTION:

The structural analysis should guide the design of the any structural components like (spacecrafts, airplane parts or pressure vessel) and provide a high degree of confidence. The analysis should be an integral part of the design process, thus minimizing design effort and time by eliminating redesign caused by failure during structural verification testing. An important benefit of performing stress analyses is the ability to determine design sensitivities and to conduct trade studies. Thus, effective optimization of the structure can be achieved, enhancing reliability while reducing cost and weight. Openings/cut-outs are made into structures in order to satisfy some service requirements, results in strength degradation. In practice different shape of holes are used for different applications for an example manhole of any pressure vessel is either circular or elliptical while the window or door of an airplane is rectangular hole having chamfer of some radius at corners. This hole/opening works as stress raisers and may lead to the failure of the structure/machine component. Hence it is an important aspect of stress analysis to predict stress concentration for regular or irregular holes. The irregularity in the hole shape may be because of chemical degradation. Under the effect of external loading and chemical process some irregular shapes may evolved. It is necessary to know stress distribution around such irregular shaped hole which may be useful to know hole shape evolution.

Stress concentration is localization of high stresses mainly due to discontinuities in continuum, abrupt changes in cross section and due to contact stresses. To study the effect of stress concentration and magnitude of localized stresses, a dimensionless factor called Stress Concentration Factor (SCF), denoted as $K_t$.

$$K_t = \frac{\sigma\ max}{\sigma\ nom}$$

Where, $\sigma_{max}$ is maximum stress at the discontinuity and $\sigma_{nom}$ is nominal or background stress. The stress concentration factor can be determined analytically by applying elasticity theory. [1]

Stress analysis of the critical elements under various loading conditions is carried out by the researchers for safe design of the element. Stress is measured by experimental methods or analytical/numerical methods.

### 1.1 PROBLEM DEFINITION:-

Plates and shells of various constructions find wide uses as primary structural elements in aerospace, mechanical and civil engineering structures. In recent years, the increasing need for lightweight efficient structures has led to structural shape optimization. Different cut-out shapes in structural elements are needed to reduce the weight of the system and provide access to other parts of the structure. It is well known that the presence of a cut-out or hole in a stressed member creates highly localized stresses at the vicinity of the cut-out. The ratio of the maximum stress at the cut-out edge to the nominal stress is called the stress concentration factor (SCF). The understanding of the effects of cut-out on the load bearing capacity and stress concentration of such plates is very important in designing of structures.

### 1.3 OBJECTIVES OF PROJECT:-

a) To find out the SCF for different shaped cutouts by FEA analysis method.
b) To find out the SCF for different shaped cutouts by strain gauge method.

c) To find the maximum stress concentration localization area for different shaped cutouts.
d) To analyses the effect of bluntness and orientation of cutout on SCF.
e) To compare the SCF results of analytically and experimentally methods.

## 2. LITERATURE REVIEW:

*J. Rezaeepazhand N, M. Jafari:* This paper describes that the high stress concentration at the edge of a cutout is of practical importance in designing of the engineering structures. The SCFs of these type cutouts usually are determined either experimentally or numerically using finite element methods. The simple analytical stress analysis presented in this study provides a numerical result for stress concentration factors for perforated isotropic plates with a special shaped cutout. Analytical and numerical studies were conducted to investigate the effects of variation in cutout shape (triangular, square and pentagonal), cutout orientation, and bluntness and load direction on the values of SCF in flat plate under uniaxial tension load. Leknitskii's solution for circular and elliptical cutouts is extended to special cutout shape using complex variable mapping. This complex variable function can be used in modeling and evaluation of stress distribution in perforated isotropic plates. This method proved to be efficient for solving a number of problems with various special shaped cutouts. The results presented herein indicated that the stress concentration factor of perforated plates can be significantly changed using proper cutout shape, bluntness and orientation. For a wide range of bluntness, the desirable SCFs of square cutouts are less than the SCF of similar plates with a circular cutout. However, SCFs of triangular and pentagonal cutout are always more than the corresponding value of a circular cutout. Hence, a rectangular cutout is more efficient than triangular and pentagonal cutouts.

*Jinho Woo and Won-Bae Na:* In this paper, the stress concentration analyses of perforated steel plates with various shapes, bluntness, and rotation of polygonal cutouts is explained. For the analysis intentionally limit resulting stresses in an elastic range by controlling the applied uniaxial tensile forces. It is concluded that the maximum stress in the perforated steel plate with the circular cutout is about three times the applied force. From the finite element analyses, they had concluded that, depending on cutout shapes, bluntness and rotation effects on stress concentration vary. However, in general, as bluntness increases, the stress concentration increases, regardless of the shape and rotation. A more important finding is that the stress concentration increases as the cutouts become more oriented from the baseline, which is the positive horizontal axis (+x) and one of the directions of the applied tensile forces. This fact demonstrates that the orientation is also a relatively significant design factor to reduce stress concentration. In general, in the case of the triangle cutout, it is preferable to orient one side of the triangle cutout to be perpendicular to the applied tensile forces. Similarly, in the case of the square cutout, it is more advantageous to orient two sides of square cutout to be perpendicular to the applied tensile force. Therefore, at the design stage, determining the direction of a major tensile force is required. By aligning these polygon cutouts properly, we can then reduce stress concentration. This finding is mainly for uni-axial tensile forces in an elastic range.

*Patel Dharmin, Panchal Khushbu and Jadhav Chetan:* In this research, investigations that have been made on the "stress analysis of an infinite plate with cut-outs". A number of analytical and experimental techniques are available for stress analysis around the different types of cut-outs for different condition in an infinite plate, made up of different materials under different loading condition has been reported in this article. The methods compared are tabulated with their findings. Singularities of circular hole in rectangular plate and elliptical hole in rectangular plate are considered.

*M Mohan Kumar, Rajesh S, Yogesh H and Yeshaswini B R:* This paper describes that the plates with variously shaped cut-out are often used in engineering structures and the understanding of the effect of cut-out on the load bearing capacity and stress concentration of panels is very important in designing of structures. Different cut-out shapes in structural elements are needed to reduce the weight of the structure or provide access to other parts of the structure. Extensive studies have been carried out on stress concentration in perforated panels which consider cut-out shapes, boundary conditions and bluntness of cut-outs. This study focuses on the stress concentration analysis of perforated panels with not only various cut-outs and bluntness but also different cut-out orientations. Therefore, at the design stage, once the direction of a major tensile force is known, the cut-outs can be aligned properly based on the findings of the work to reduce the stress concentration at the cut-outs thereby increasing the load bearing capacity of the panel.

*Murilo Augusto Vaz, Julio Cesar Ramalho Cyrino and Gilson Gomes da Silva:* In this paper the three-dimensional stress concentration factor (SCF) at the edge of elliptical and circular holes in infinite plates under remote tension has been extensively investigated considering the variations of plate thickness, hole dimensions and material properties, such as the Poisson's coefficient. This study employs three dimensional finite elements modelling to numerically investigate the effect of plate width on the behaviour of the SCF across the thickness of linear elastic isotropic plates with a through the thickness circular hole under remote tension. The problem is governed by two geometric non-dimensional parameters, i.e., the plate half-width to hole radius (W/r) and the plate thickness to hole radius (B/r) ratios. It is shown that for thin plates the value of the SCF is nearly constant throughout the thickness for any plate width. As the plate thickness increases, the point of maximum SCF shifts from the plate middle plane and approaches the free surface. When the ratio of plate half-width to hole radius (W/r) is greater than four, the maximum

SCF was observed to approximate the theoretical value determined for infinite plates. When the plate width is reduced, the maximum SCF values significantly increase. A polynomial curve fitting was employed on the numerical results to generate empirical formulas for the maximum and surface SCFs as a function of W/r and B/r. These equations can be applied, with reasonable accuracy, to practical problems of structural strength and fatigue, for instance.

## 3. EXPERIMENTATION AND METHODOLOGY:

### 3.1 OBJECTIVES OF THE PRESENT INVESTIGATION:-

In order to reach the goal, this study comprises several objectives as follows:

- To evaluate the stress concentration factor for different shaped cutouts like square, triangular, circular and elliptical.
- To find the maximum stress concentration localization area for different shaped cutouts.
- To analyses the effect of bluntness and orientation of cutout on SCF.
- To compare the SCF results of analytically and experimentally methods.

For finding out the stress concentration region or Stress concentration factor an analytical (Finite Element Method) and experimental (Electrical Strain Gauges) methods are used.

### 3.2 STRESS CONCENTRATION PROBLEM:-

Stress concentration due to holes, cuts, notches and other imperfections in an elastic body in 2d can be considered a special case of plane problems. Consider the case of an infinite plate in uniaxial tension ¯¯⊓¯T as illustrated below (Nash, 1987):

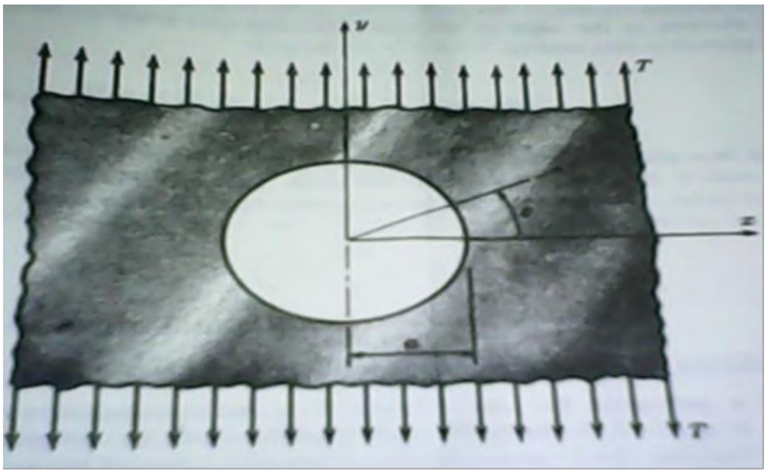

Fig. 3.1: Infinite plate uni-axially loaded and with hole at centre

It has been shown that the state of stresses is given by the following equations:

$$\sigma_r = \frac{\sigma}{2} [ 1 - \frac{a^2}{r^2} - ( 1- \frac{4a^2}{r^2} + \frac{3a^4}{r^4} ) \cos 2\theta] \quad (3.1)$$

$$\sigma_\theta = \frac{\sigma}{2} [ 1 + \frac{a^2}{r^2} + ( 1+ 3 \frac{a^4}{r^4} ) \cos 2\theta] \quad (3.2)$$

$$\tau_{r\theta} = \frac{\sigma}{2} [ 1 + 2 \frac{a^2}{r^2} - \frac{3a^4}{r^4} ) \sin 2\theta] \quad (3.3)$$

Considering the boundary conditions, at the boundary of the hole, r = a, it can be seen from above that both $\sigma_r$ and $\tau_{r\theta}$ vanish. At points far removed from the hole, as r→∞, the state of stress becomes:

$$\sigma_r = \frac{\sigma}{2} [ 1 - \cos 2\theta] \quad (3.4)$$

$$\sigma_\theta = \frac{\sigma}{2} [ 1 + \cos 2\theta] \quad (3.5)$$

$$\tau_{r\theta} = \frac{\sigma}{2} \sin 2\theta \quad (3.6)$$

Which correspond to a state of a bar/plate in uniaxial tension with a plane at an arbitrary angle $\theta$ with normal stress $\sigma = \sigma_r$ and shear stress $\tau = \tau_{r\theta}$. Therefore a point far removed from the hole does not experience the effects of stress concentration. (Saint Venant's principle) (Nash, 1987).

Another feature of interest is examining the tangential stress at $\theta = 0$ and $\theta = \pi$ at $r = a$, that is an element at the edge of the hole. The tangential stress is in the direction of the applied tensile loading. From the above equations we get:

$$[\sigma_\theta]_{\theta=0,\pi}^{r=a} = 3\sigma \quad (3.7)$$

That is a small hole in an infinite plate subject to uniaxial tension causes maximum normal stress three times that which would exist if the hole was not present in the plate. While a more rigorous take on stress concentration can be found in Timoshenko (1956), an alternative treatment of the stress concentration problem in given by Nisbett (2006) who defines a practical stress concentration factor, the geometric stress concentration factor given as:

$$K_t = \frac{\sigma_{max}}{\sigma_0} \quad (3.8)$$

This relates the actual maximum stress at discontinuity to the nominal stress, which is defined as below:

$$F = \sigma w t \quad (3.9)$$

$$\sigma_0 = \frac{F}{(w-d)t} = \frac{w}{(w-d)}\sigma \quad (3.10)$$

This stress concentration factor has no dependence on the material employed hence the name theoretical or geometric concentration factor. Nisbett (2006) note that the analysing geometric shapes to determine stress concentration factors is difficult problem. Most concentration factors are found by experimental techniques with the works of Pilkey (1997) being recommended.

**3.3 EXPERIMENTAL SET UP:-**

Experimental setup consists of a loading frame for applying load to a specimen; load is applied by means of screw as shown in Fig.3.3. Fig.3.2 is a CATIA model of experimental setup and Fig.3.3 shows actual experimental setup. Specimen is prepared of Aluminum alloy material plate of size 360 X 75 X 3 mm having centrally square, elliptical and circular cutouts as shown in following fig.

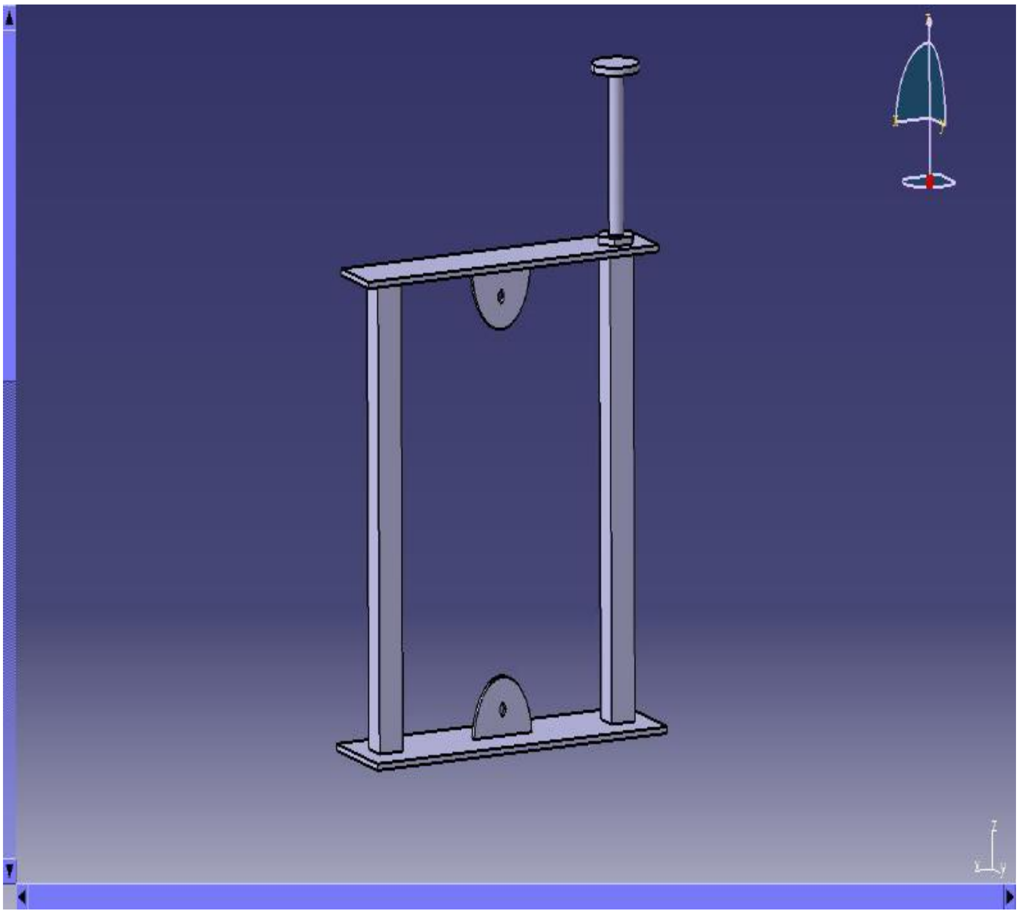

Fig.3.2 CATIA model of experimental setup (loading frame)

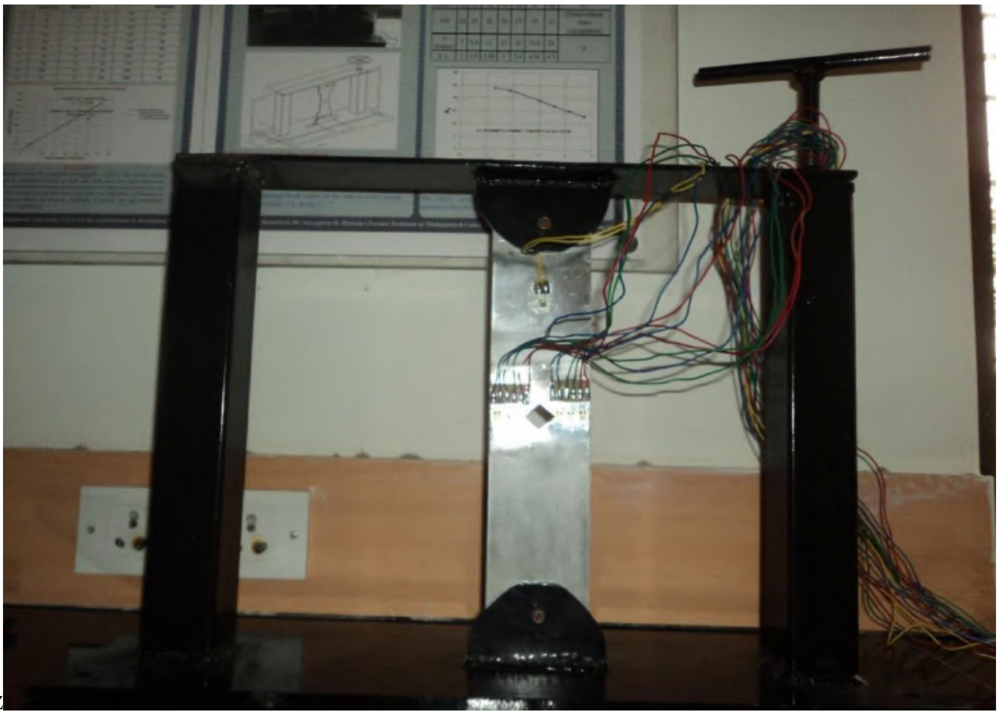

Fig.3.3. Actual experimental setup

**3.3.1Preparation of Specimen (Square Cutout):-**

The material of plate is Aluminum alloy selected because it is generally used in aerospace for light weight application for example like space shuttles, aeroplanes etc. of size 360 X 75 X 3 mm as shown in Fig 3.4.

Table 3.1 Material properties of Aluminum alloy

| | |
|---|---|
| Young's modulus (GPa) | 71.0 |
| Poisson ratio | 0.33 |
| Tensile yield strength (MPa) | 280 |
| Tensile ultimate strength (MPa) | 310 |

On this plate two circular holes of dia 10 mm at the near to end of this plate are drilled for clamping purpose. A centrally square hole in a plate of side 15 X15 mm is made with help of (W-EDM) machine to control the internal residual stress near to the cutout which is negligible in this case. After this strain gauge of 120 Ω resistances are taken for the mounting purpose near to the high stress localized area which is got from the Ansys results for measuring the corresponding strain value.

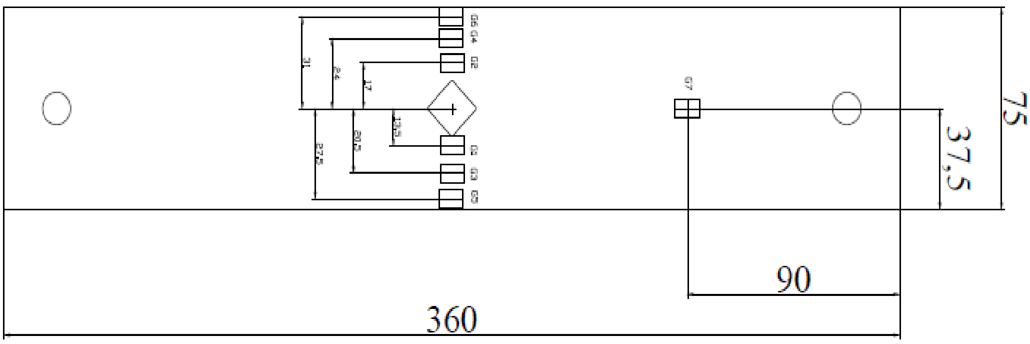


Fig.3.4. Drawing for square cutout and strain gauge mounting

Procedure for strain gauge mounting is as follows-

**a) Surface preparation**

Cleaning surface: - Removing the grease and oil on the specimen surface by using solvent like Alcohol, Acetone, or some other degreasing agent.

Abrading surface: - Silicon-carbide paper is used to sand away uneven surface, and smooth the gauging area. Usually 320 grit first, and then followed by 400 or finer grit.

Marking layout lines: - By using a clean rule and a fine pencil the layout lines, are drawn where the strain gauges are to be mounted.

**b) Gage bonding**

Preparing gage: - By using tweezer the gauges are taken out from folder containing gauges and placed on the clean working area with the bonding side down.

Transferring gage: A cellophane tape is used to pick up the strain gage and transfer it to the gaging area of the specimen and aligned the gages with the layout lines.

Applying catalyst: - Lifted one end of the tape such that the gage does not contact the gaging area and the bonding site is exposed and applied the catalyst evenly and gently on the gage.

Applying adhesive: - By applying enough adhesive to provide sufficient coverage under the gage for proper adhesion. Place the tape and the gage back to the specimen smoothly and gently. Immediately place thumb over the gage and apply firm and steady pressure on the gage for at least one minute.

Removing tape: - Cello tape is place at least two more minutes after the thumb was removed and peels the tape from the specimen slowly and smoothly from one end to the other end.

**c) Lead wire attachment**

Stripping lead wire: - By Cutting the lead wires to the desired length. Strip off the 2 - 3 cm (1 in) insulation for attachment and then after twist each bundle of conductors together.

Tinning lead wires: - By keeping the soldering station to the proper temperature, the solder pencil / gun is kept to melt a pool of fresh solder and coated the non-insulated parts of the lead wires with solder.

Tinning gage: - Placed the solder on the copper tabs of the gage. Press the heated solder pencil through the solder to the tabs. A smooth hemispherical "solder pillow" will be formed in this tinning operation. However, the solder pencil should not contact the strain gage tabs for more than 2 seconds at a time.

Attaching lead wire: - Positioning the non-insulated conductors directly on top of the solder pillow and press the piece of tape to the end of lead wire insulation to fix the lead wires at right position of the specimen. Press the solder pencil on the conductor and push it into the solder pillow.

Final specimen after strain gauge mounting is shown in following Fig. 3.5.

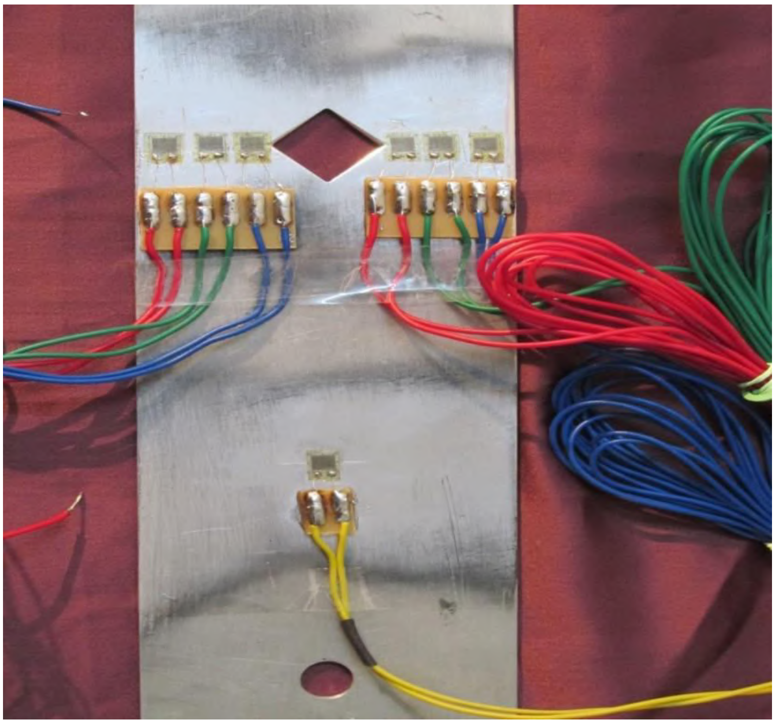

Fig.3.5. Square cutout specimen

**3.3.2. Preparation of Specimen (Ellipse Cutout):-**

The material of plate is Aluminum alloy selected because it is generally used in aerospace for light weight application for example like space shuttles, aeroplanes etc. of size 360 X 75 X 3mm as shown in Fig 3.6. On this plate two circular holes of dia 10 mm at the near to end of this plate are drilled for clamping purpose. A centrally elliptical hole in a plate of major axis 20 mm and minor axis 10 mm (major axis parallel to applied force) is made with help of (W-EDM) machine to control the internal residual stress near to the cutout which is negligible in this case. After this the strain gauges of 120 Ω resistances are taken for the mounting purpose near to the high stress localized area which is got from the Ansys results for measuring the corresponding strain value.

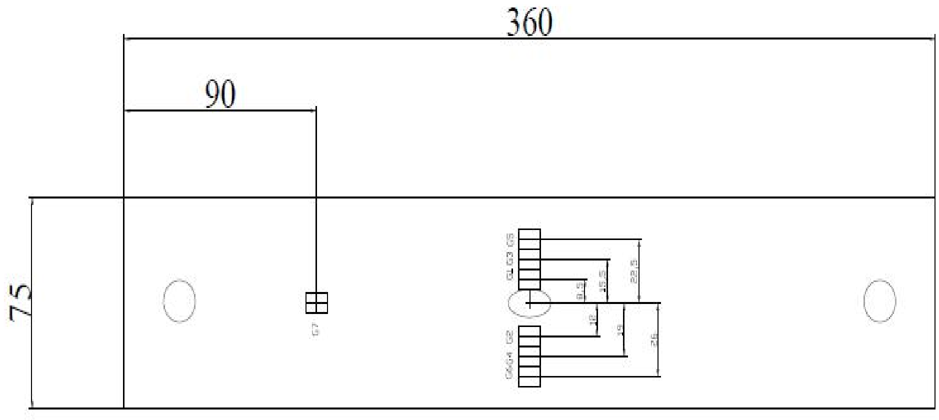


Fig.3.6. Drawing for ellipse cutout and strain gauge mounting

Same strain gauge mounting procedure is again done on this specimen as before explained in square cutout and final specimen after strain gauge mounting is shown in following Fig. 3.7

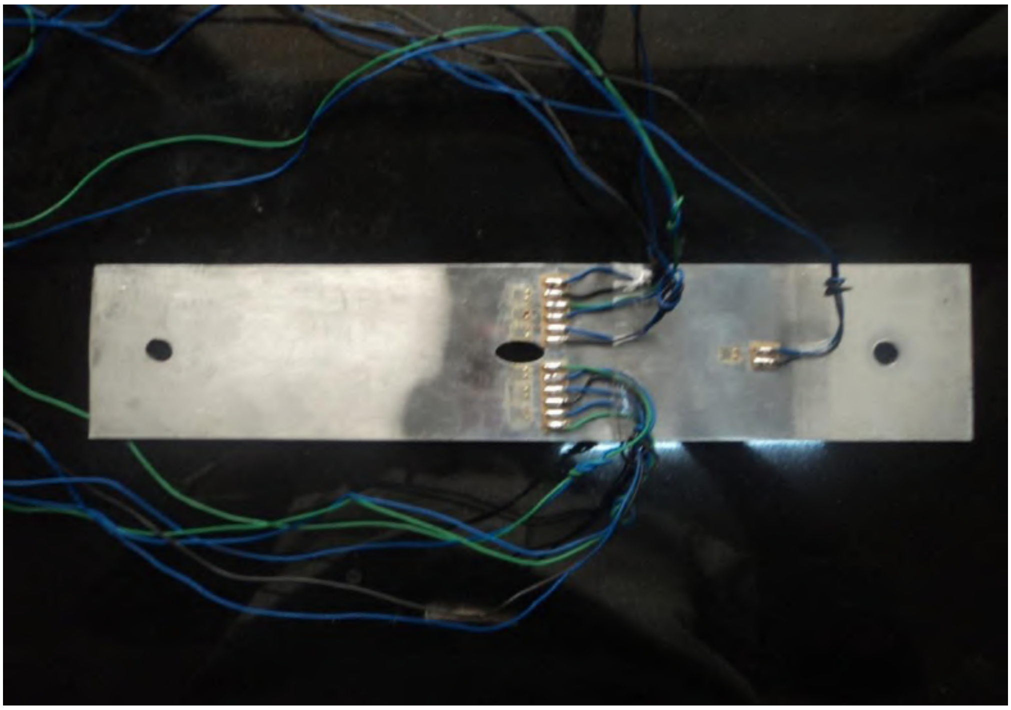

Fig.3.7.Elliptical cutout specimen.

Experimentation can be done for detection of SCF of different cut-out and orientation for different notches like circular, square, triangular and elliptical by changing radius ratio and angle of orientation etc. The experimentation can be done first in software that is ANSYS and its validation can be done practically by electrical strain gauges.

During experimentation the parameter that is radius ratio and orientation of notch can be varied as follows.

1) Bluntness ( $\frac{r}{R}$ ):- 0.1 to 1.0

2) Orientation of cut-out: - 0° to 90° (Depend on the shape of cut-out / notch)

3) Cut-out will be in the shape: - circular, square, triangular and elliptical. [5-6]
For FEA experimentation there will be some standard procedure to follow which has been explained with the help of following flowchart.

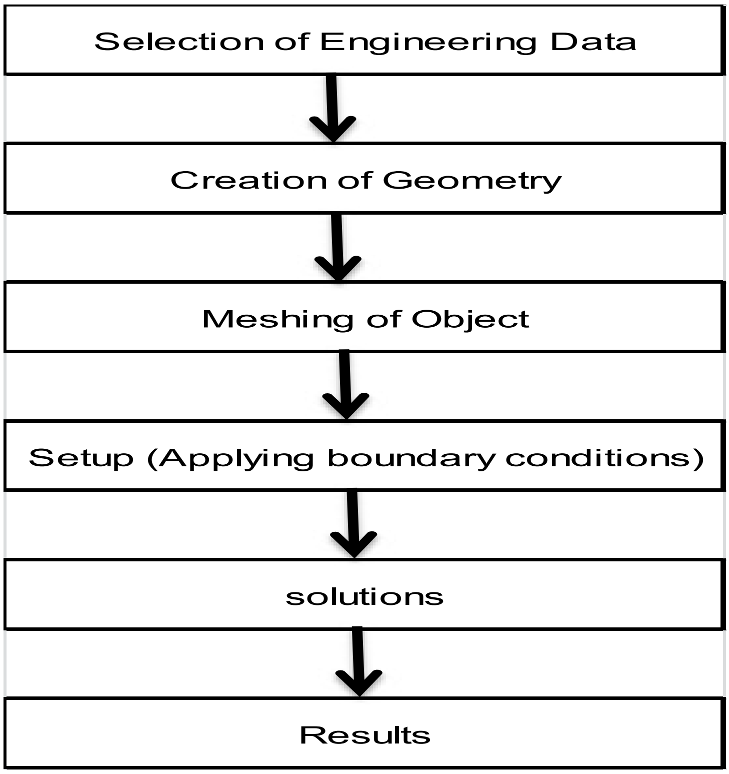


Fig.3.8. Flow chart for FEA experimentation

During FEA we have to follow some standard steps for that, shown in above fig. 3.8. First the selection of engineering material that is engineering data collection is done then creation of geometry is done in modeling, then next step is meshing of created geometry by using different meshing methods like mapped face meshing, automatic method etc. After meshing the boundary conditions are applied like applying loads, fixed supports and applying constraint equation etc. then after applying boundary conditions the equations are solved according to conditions that is solutions and we can get the respective results like stresses, displacements, strain etc.

## 4. RESULT AND DISCUSSION:-

With the experimentation on different shaped cutout the following results are acquired by FEA method and experimental (Electrical strain gauge method) which are discussed successively.

### 4.1. SQUARE CUTOUT:

For square cutout the following parameters are consider for experimentation
Parameters:-
Bluntness (w) - 0.1, 0.25, 0.3, 0.5, 0.75, 0.9 and 1.0
Orientation - 0˚, 15˚, 30˚, 45˚, 60˚, 75˚, and 90˚
Following Fig 4.1 shows the square cutout and ϕ is the angle of rotation with respect to x axis the square cutout is rotated counter clockwise like 0˚, 15˚, 30˚, 45˚, 60˚, 75˚ and 90˚, for different values of bluntness like 0.1, 0.25, 0.3, 0.5, 0.75, 0.9 and 1.0. Fig 4.2 shows the different rotational conditions of the cutouts

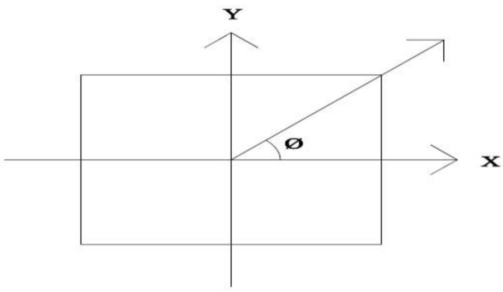


Fig.4.1 Rotation of square cutout

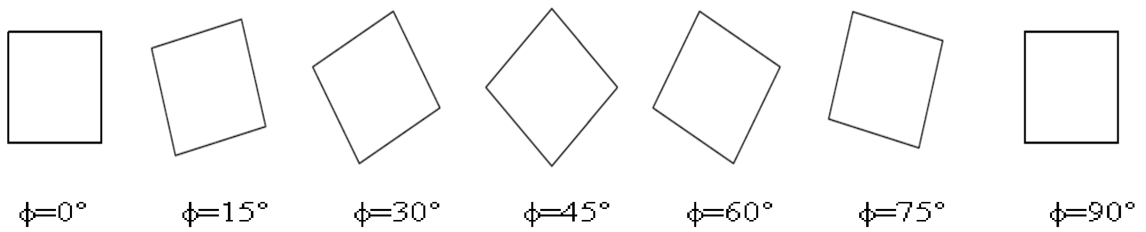


Fig.4.2 Rotated cutouts for square

For a square shape the acute angle between two sides is 90 ˚ so that we can rotate a square only up to 90 ˚ after it can come on a same position same as on 0 ˚ that is for ϕ=0˚ or ϕ=90˚ will be the same geometry. In this case 0 ˚ means any two opposite sides of a square are parallel to the applied load (force) direction is considered.

### 4.1.1. ANSYS 14.5 Results For Square Cutout

a) Bluntness 0.1:-

Bluntness 0.1 means ( $\frac{r}{R}$ ) = 0.1 , in this case r means fillet radius and R means inscribed circle radius now, in this case we have taken the square cutout of dimension 15 X 15 mm, for that the inscribed circle radius is 7.5mm.

Now we have, w (bluntness) = $(\frac{r}{R})$ = 0.1 (4.1)

We know w = 0.1

R = 7.5

Therefore $0.1 = \frac{r}{7.5}$

r = 0.75

Therefore fillet radius for this condition is 0.75 is taken according to above calculations. The model of specimen is created in Ansys 14.5 workbench modeling and then after meshing is done for a specimen with a node 8111 and element size 1088.

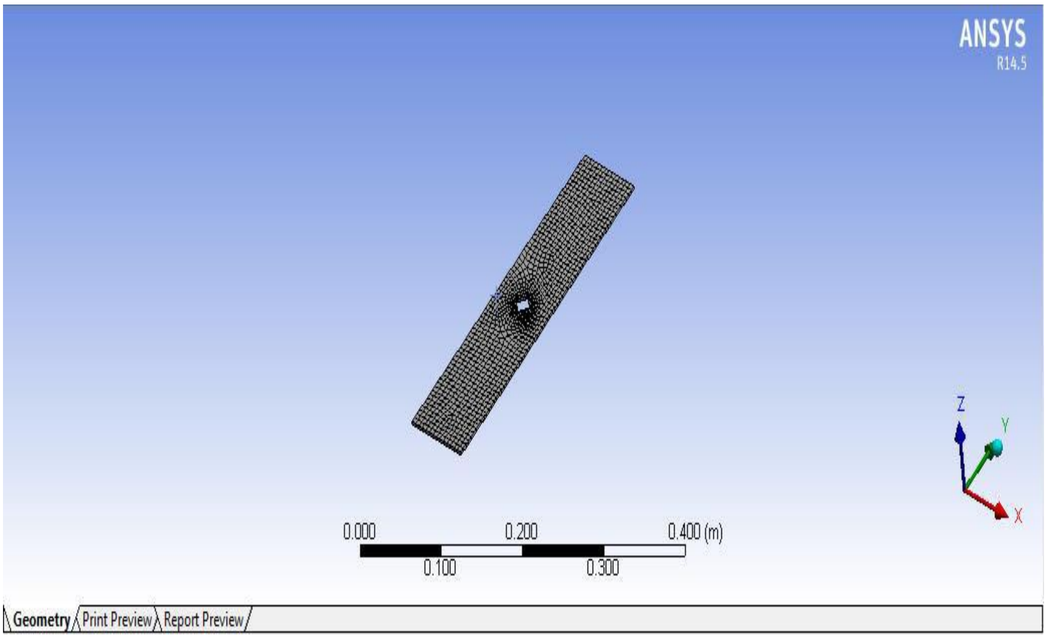


Fig.4.3 Meshed square cutout (when w=0.1)

One end of specimen is fixed and at other end the pressure is applied 1MPa and the results are collected which are as follows

For 0˚,

$$K_t = \frac{\sigma \max}{\sigma \text{nom}}$$

$$= \frac{3263364.509}{1000000}$$

$$= 3.263364509$$

From above procedure for all angle of rotation the SCF value is calculated similarly, and shown in the following table.

Table 4.1 SCF for square cutout w = 0.1

| Angle of Rotation (˚) | Maximum Stress (Pa) | SCF |
|---|---|---|
| 0 | 3263364.509 | 3.263364509 |
| 15 | 4954324.856 | 4.954324856 |
| 30 | 6651487.27 | 6.65148727 |
| 45 | 7375160.834 | 7.375160834 |
| 60 | 6508823.732 | 6.508823732 |
| 75 | 4879617.005 | 4.879617005 |
| 90 | 3293027.811 | 3.293027811 |

From the above results the graph is plotted against the maximum stress vs angle of rotation for bluntness value 0.1. As shown in following Fig.4.4

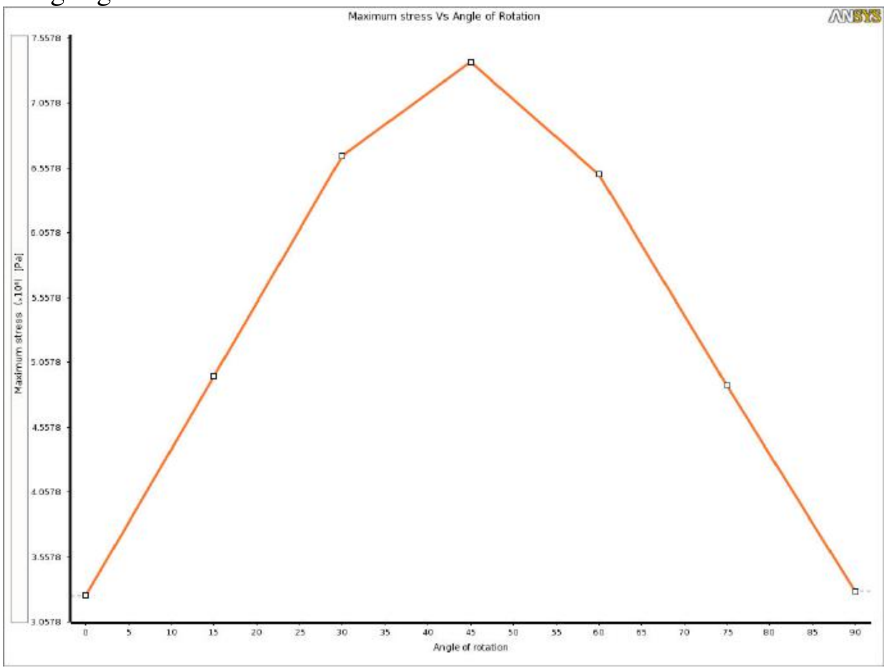


Fig.4.4 Maximum stress Vs Angle of rotation for w = 0.1

In above graph on x- axis angle of rotation in degree is taken and on y- axis maximum stress in MPa is taken, this graph is plotted in Ansys 14.5 tool. From the above graph it is cleared that the SCF will vary with respect to the change in angle of a rotation for a specific bluntness value, for a square cutout with bluntness 0.1 the maximum stress is observed, which is 7375160.834 Pa (that is SCF value is 7.37) when square cutout is inclined at 45˚ with respect to the fixed end as shown in following fig, and minimum stress is observed, which is 3263364.509 Pa (that is SCF value is 3.26) when square cutout is at 0˚ that is it's any two opposite sides will be parallel to the applied force. From following fig.4.5 it is cleared that the for square cutout with w = 0.1, near to two opposite corner of a square which are on vertical central axis of a square cutout the stress localization will be very less (shown in blue coloured bubbles on both side) compared to any other region in plate and other two opposite corners have maximum stress localization (shown in red mark).

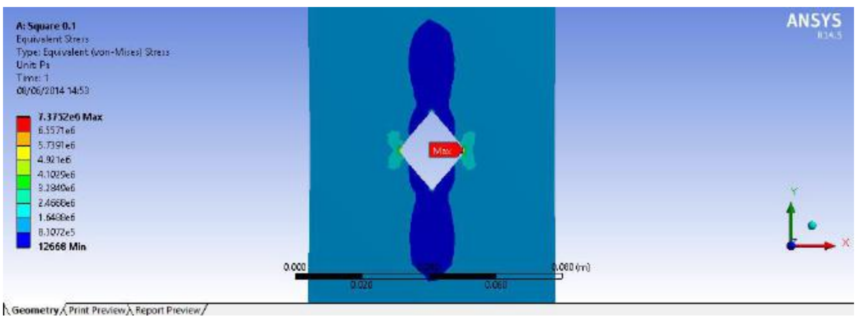


Fig.4.5 Maximum stress contour for square cutout (when w = 0.1)

The above procedure is repeated for different bluntness values 0.1, 0.25, 0.3, 0.5, 0.75 and 0.9 etc

From above results a combine graph is plotted of SCF vs Angle of rotation for all bluntness value (w= 0.1, 0.25, 0.3, 0.5, 0.75, 0.9 and1.0) shown in following Fig.4.6

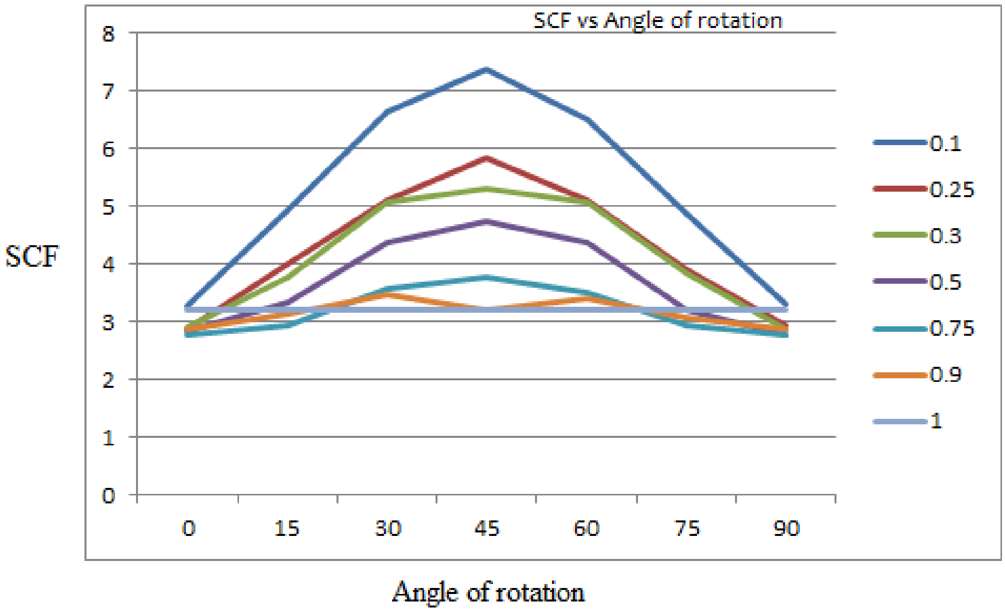


Fig.4.6 SCF Vs Angle of rotation for square cutout

From above graph it is cleared that the SCF is changes with the angle of rotation for all value of bluntness, for bluntness value the 0.1, 0.25, 0.3, 0.5 and 0.75 the SCF value is maximum at 45˚ respectively and also at 45˚ the SCF value will be decreases from 7.37 to 3.76 (for w = 0.1, 0.25, 0.3, 0.5 and 0.75). For w = 0.9, means this shape is near equal to circle (approximately like a square with negligible side length) and hence the SCF will be varies near about the value equal to 3.0, when w = 1.0 that means it will be a pure circular shape the SCF will remain constant throughout for the all angle of rotations, and the SCF value will be 3.19.

**4.2 EXPERIMENTAL VALLIDATION (Electrical strain gauge method):-**

Electrical strain gauge method is used for finding out the stress concentration factor for square cutout with w=0.1, θ= 45˚ the experimental setup is shown in following Fig.4.7. P3 strain module Vishay make (Strain indicator) is used for strain measurements.

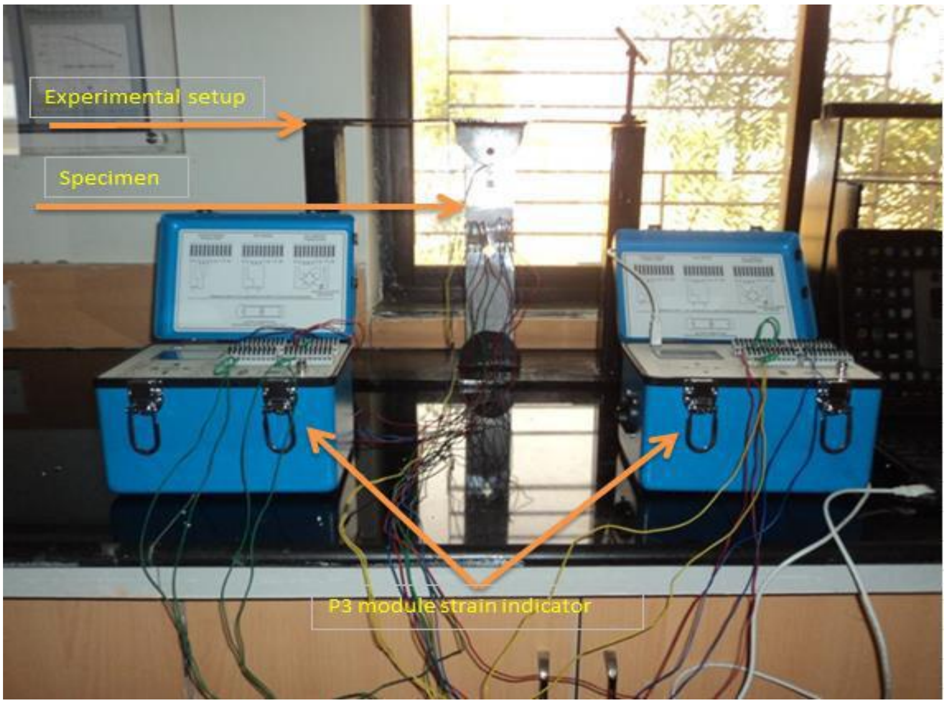


Fig.4.7 Electrical strain gauge method for square cutout

Description – There are total of 6 strain gauges that are bonded along transverse axis of symmetry starting from close to square edge to the right end of transverse axis. Since the gauges cannot be bonded exactly at the edge of square hole at right transverse edge, a polynomial is fitted to the data to extrapolate the strain to an edge as explained in procedure below, another single gauge is bonded in the middle portion of the specimen (i.e. between hole and load) to measure average strain.

## 5. CONCLUSIONS:

From above experimentation is cleared that, we can control the SCF value by changing the parameters like bluntness, cutout shape and orientation of cutout with respect to applied force,

For square cutout the maximum SCF value is 7.37(FEA) and 7.54 (Experiment strain gauge method), when bluntness is 0.1 and θ = 45˚. We know generally for circular cutout the SCF value is 3, from above experimentation it is noted that for square cutout SCF value can be reduced to 3 when bluntness value 0.25, 0.3, 0.5, 0.75 and 0.9 (and θ = 0˚ or 90˚) that means any two opposite sides of a square must be parallel to applied force at this condition SCF value is minimum for any bluntness value.

## 6. FUTURE SCOPE:

The SCF for square, circular cutout can be reduced by introducing square and circular shapes in elliptical shape, and it is possible to check the effect of different bluntness factor for all corners of a square (i.e. square have a four corners , the bluntness value for all four corners will be different)

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