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RESEARCH ARTICLE

EXPERIMENTAL VERIFICATION OF STRESS CONCENTRATION FACTOR IN AN UNFLAWED LUG USING UNIFORM & GRADED MESH OF 2D LINEAR & NON-LINEAR ANALYSIS USING MSC.NASTRAN / MSC.PATRAN.

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Abstract

The objective of the current investigation is to study the variation of Stress Concentration Factor in an unflawed Lug Joint that finds application in linkage structures or to complete the structural assembly in an Aircraft, so that the loads can be transferred from one structural member to another. Because when the loads are transferred from one structural member to another due to the pressure distribution on the Aircraft because of the service load, the stress concentration becomes so high that at the edges of the hole, there is a possibility that can initiate a minute crack. Suppose in case, if the crack gets unnoticed during Maintenance checks, then due to the service loads, there is a chance of the occurrence of Structural failure due to crack propagation that could cause a catastrophe. Hence it becomes important to investigate the Lug joints for Stress Concentration Factor.

Introduction:-

Lug joints are preferred not only in Aerospace and Aviation industry but also in Automobile, Machineries, Civil and Marine industries. In Aviation industry, The most commonly used joints are Lug Joints, Lap Joints and Adhesively Bonded Joints, that are used to connect the structural components so that the load transfer takes place from one structural member to the other. And a Lug Joint is frequently used as it is easy to attach and detach and as they are connected with a single pin or bolt to the male and female lug assembly. Since the stress concentration at the edge of the hole is maximum, a minute crack can be initiated due to the service loads that can propagate with time exponentially leading to a catastrophe if critical stress or critical crack lengths are reached. Hence it becomes necessary to design and study the Lug Joints (Kathiresan.K et al,1984a, b; Kathiresan.K et al,1984)(Gene.E.Maddux,1969).

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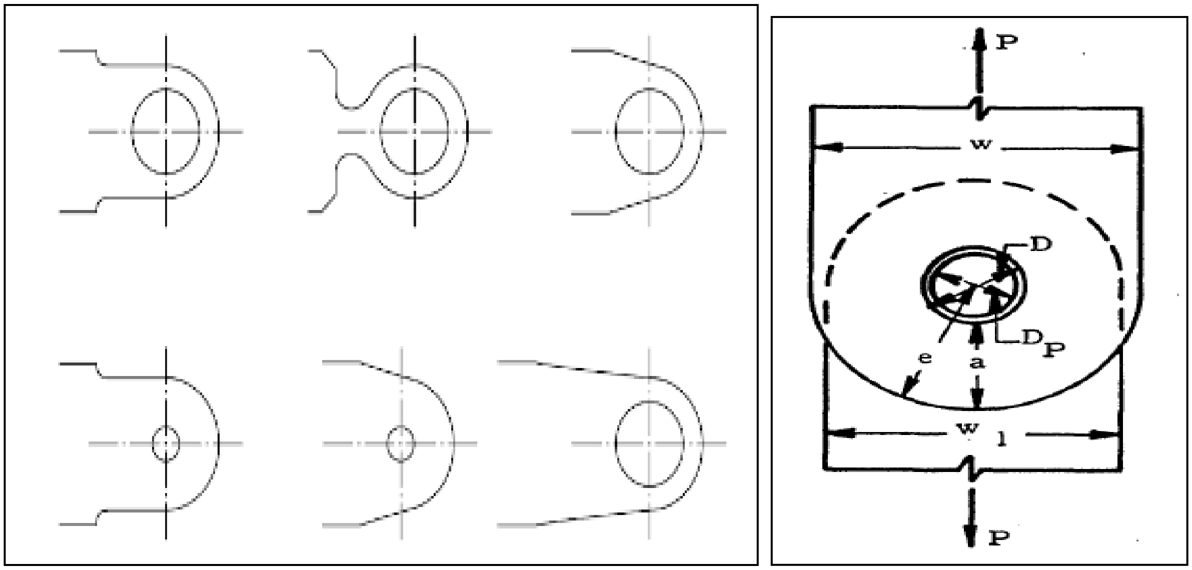


Fig 1:-Various types of Lug Joints

Literature Survey:

The loads that acts on an Aircraft in service are Aerodynamic loads, Structural loads, Propulsive loads, Thermal loads, Gust loads and g-loads that can be converted into pressure distribution on the volume of the Aircraft body which in turn can be quantified to a Variable Amplitude Stress cycles. Now these stresses has to get dissipated but before that the load transfer has to take place between the structural components which is achieved by connecting the structural components by a structural member called Joints. Most commonly used are Lug, Lap and Adhesively bonded joints. When the load transfer takes place, the stress concentration factor becomes maximum at the contact surface of the lug and hole which can create a crack initiation (Kathiresan.K et al,1984). In service, the lugs would be under axial, transverse, oblique loading conditions.

Methodology:-

A Finite Element approach is followed to compute the Stress Concentration Factor in the Lug under constant tensile loading. During Pre – processing, It involves the creation of a CAD model followed by assigning the material properties and boundary conditions. And after that load cases are inserted appropriately that gives the required results during Post - processing. It is as follows,

Problem Definition

A straight lug with the dimensions specified as shown in the table 1 is considered. Where 'R_o' is the outer radius of LUG, 'R_i' is the inner radius of LUG, 'β' is the taper angle (β = 0 for straight lug), 'L' is the distance from centre of pin to the extreme left edge and t is the thickness. Now the Stress Concentration Factor are determined using (Gene.E.Maddux,1969)(Kathiresan.K et al, 1984),

1. Uniform Mesh
2. Graded Mesh

Geometry	Dimension
R_o	39 mm
R_i, a	19.5 mm
L	100 mm
t	1mm
w	70mm

Table1:-Dimensions of the specimen

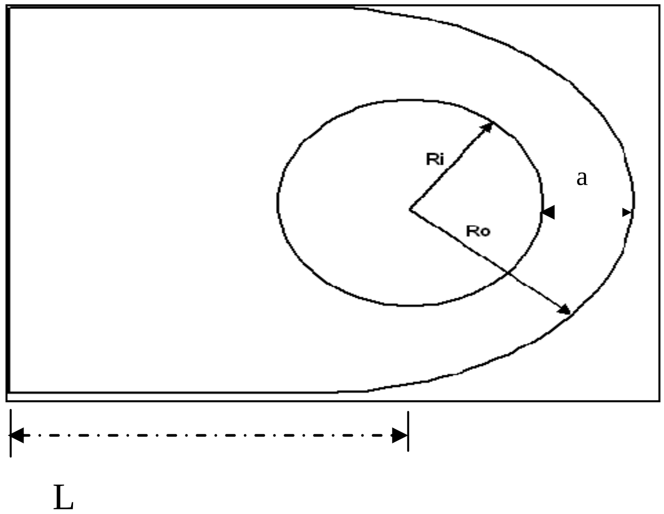


Fig 2:-Schematic view of the problem

Pre-Processing:
Geometry Creation:

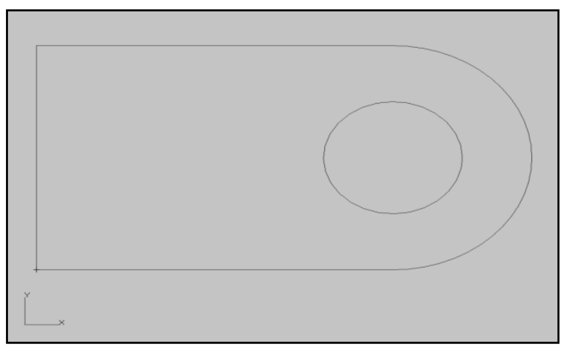


Fig 3:-Creation of geometry in MSC Patran

Creation of Groups
Three groups are created to work out with the problem easily.
1. Pin
2. Lug
3. Gap

Finite Element Meshing
Mesh the model keeping uniform mesh along the periphery between lug and pin contact (160 elements) setting the current group names individually. Mesh should be fine near the contact between Lug & Pin and can be coarse elsewhere. Renumbering nodes and elements is done followed by equivalencing nodes group-wise. Similar way the graded mesh is also generated.

Case-A: Linear Spring (Compression only) Elements for contact
The spring elements are created as bar2 elements. Nodes along the peripheries of lug & pin are set to analysis coordinate frames (Cylindrical coordinate system defined at centre). After analysis the tension springs are deleted and compression springs are retained to maintain contact between pin & lug.

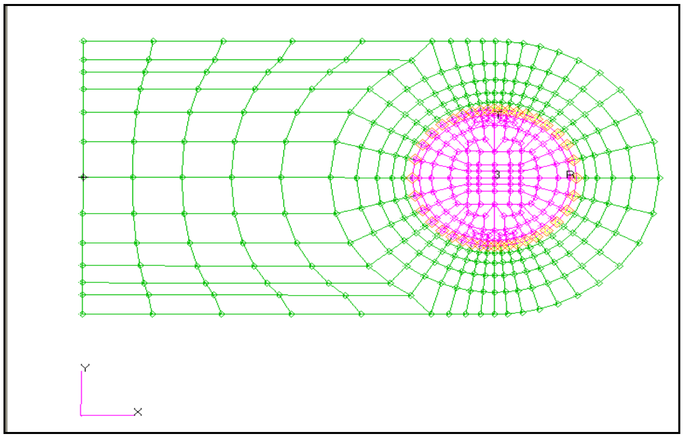


Fig 4:-Creation of groups in MSC Patran

Case-B: Linear Gap Elements for contact

The linear gap elements behave as a different MPC similar to compression springs to establish contact.

Case-C: Non-linear Gap Elements for contact

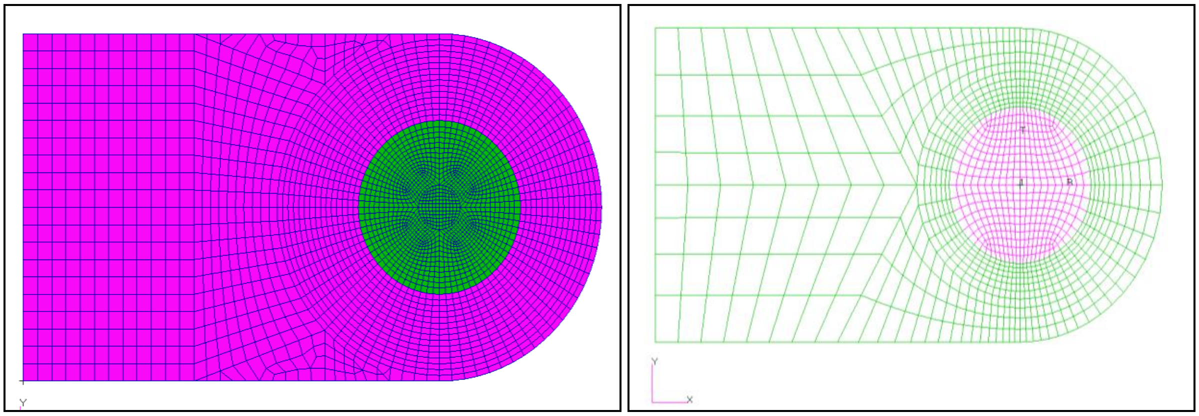
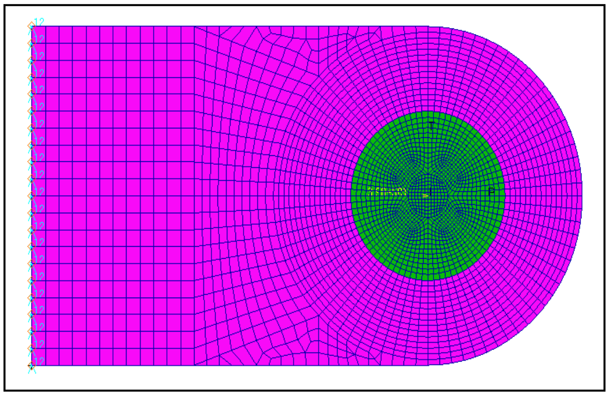


Fig 5:-Uniform Mesh & Graded Mesh - Finite Element Models

Loads and Boundary Conditions

X & Y translational displacements are fixed at the left edge of the lug.

A load of 39 N is applied at the centre of Pin along X-direction for all three cases.



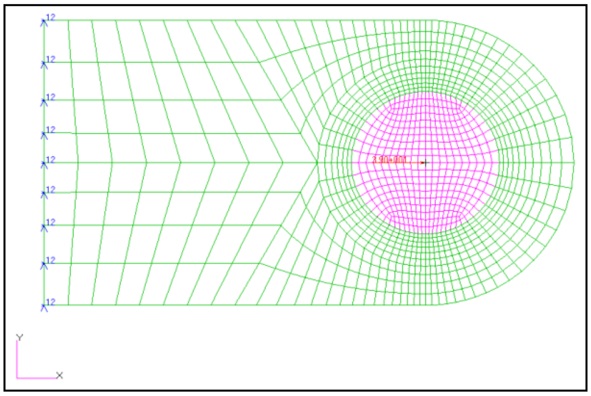


Fig 6:-Assigning Loads and Boundary Conditions (Uniform Mesh) Fig 7: Assigning Loads and Boundary Conditions (Graded Mesh)

Defining Material Properties

The material properties considered for the specimen are tabulated in the following table 2 as follows[38[[1],

Material : MS	
E	210000 MPa
υ	0.3
σ_{ys}	435
σ_u	670
Density	7850
Shear Modulus	80769.227MPa

Table 2:-Material Properties

Assigning Material Properties

The material properties assigned to all shell elements are as follows:

Case-A: Linear Spring (Compression) Elements for contact

All linear spring elements are given a stiffness of 50,000 along radial direction

Case-B: Linear Gap Elements for contact

Here, assigning properties are not required since these elements are defined as different MPC, thereby while creating elements, the properties are taken care of.

Case-C: Non-linear Gap Elements for contact

Defining GAP Properties:

		Default	Assigned
Gap properties	Initial opening (U_0)	0 (Real)	
	Preload (F_0)	0 (Real ≥ 0.0)	
	Closed stiffness (Ka)	(Real > 0)	2.72910E+07
	Open stiffness (Kb)	(10^{-14})*Ka (Real ≥ 0.0)	
	Sliding stiffness (Kt)	0.1*Ka OR Mu1*Ka (Real ≥ 0.0)	100
	Static friction (Mu1)	0 (Real ≥ 0.0)	0.1
	Kinematics friction (Mu2)	Mu1 (Mu2 ≤ Mu1) (Real ≥ 0.0)	0.1
	Max. penetration (TMAX)	0.0 (Real)	
	Max. adjust ratio (MAR)	100 (1.0 < Real < 10^6)	
	Penetration lower bound (TRMIN)	0.001 (0.0 ≤ Real ≤ 1.0)	

Table 3: Gap Properties

Creation of MSC Nastran Input File

Post Processing:

Attachment of Results

Results outputs (*.xdb) are attached to the respective Patran .db file.

Stress Concentration Factor Estimation

Description

The stress concentration factor is defined as the ratio of maximum stress to the nominal stress in the presence of a flaw/discontinuity (stress raiser). This is important in designing a component/structure.

Extraction of Results from NASTRAN

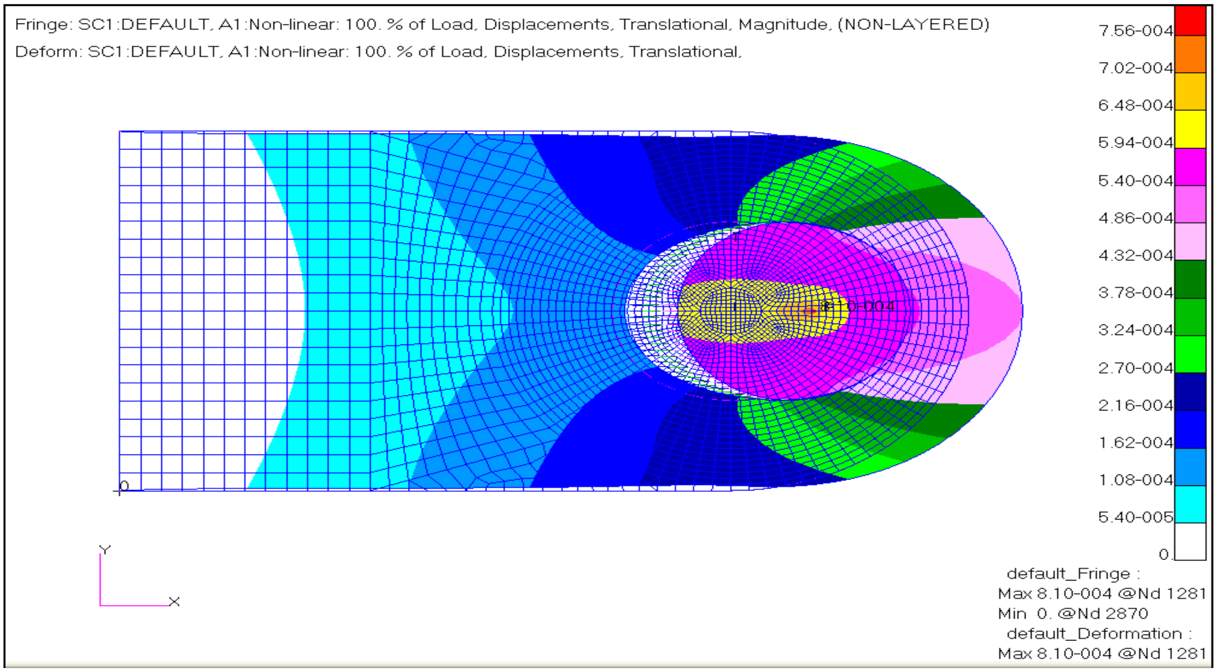


Fig 8:-Displacement plot (Uniform Mesh). The pin should not penetrate to the lug.

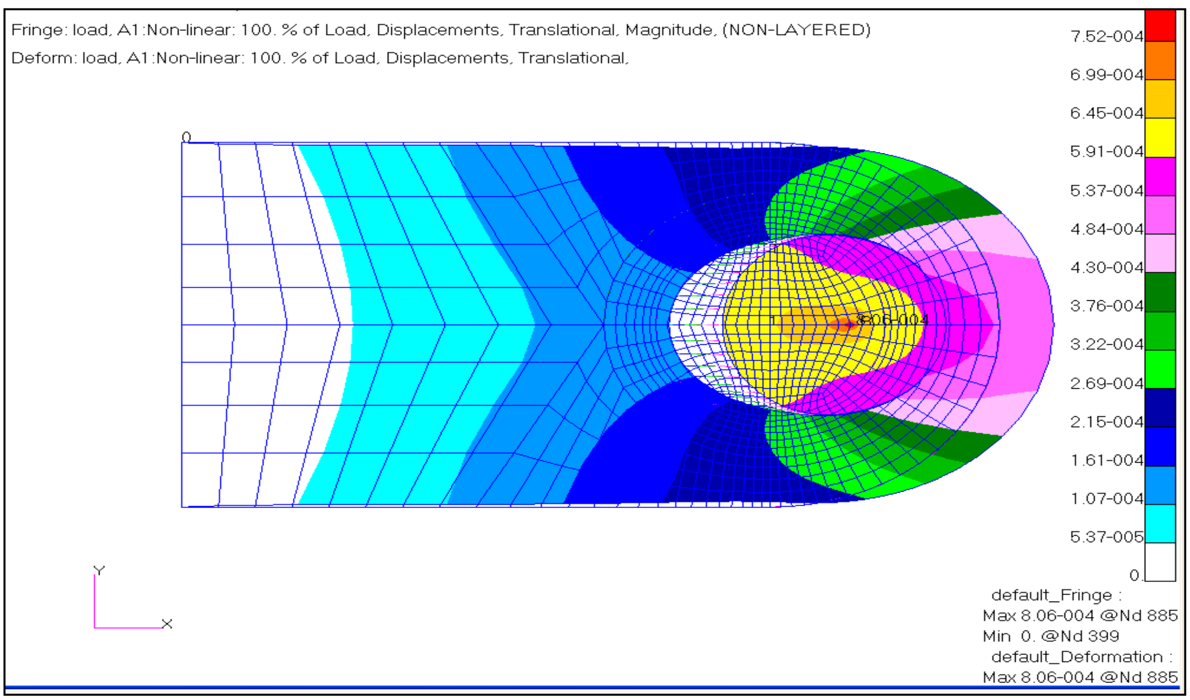


Fig 9:-Displacement plot (Graded Mesh). The pin should not penetrate to the lug.

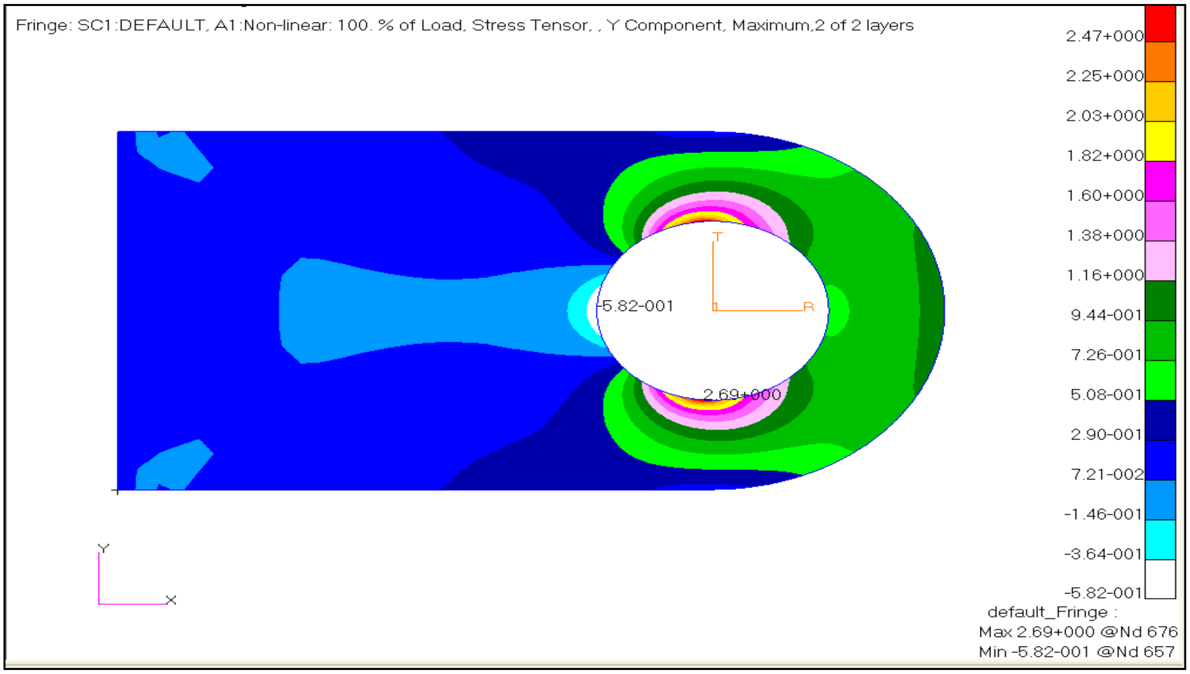


Fig 10:-Y-component stress plot in cylindrical coordinate defined at centre (Uniform Mesh).The maximum hoop (tangential) stress is found to be 2.69 MPa.

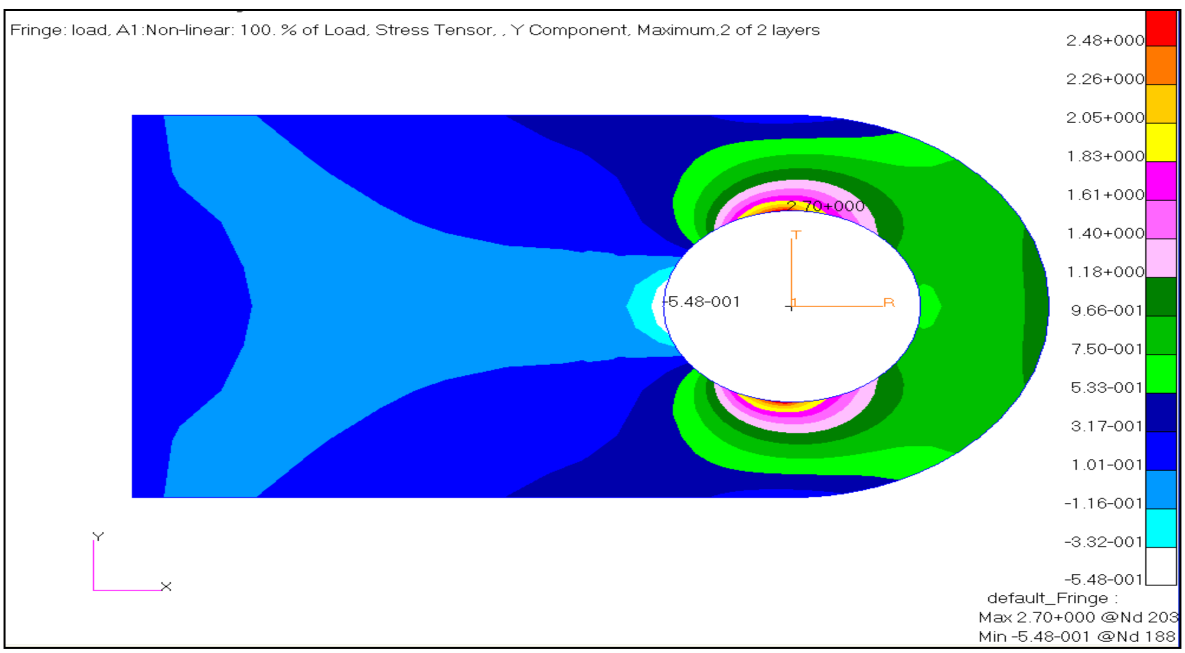


Fig 11:-Y-component stress plot in cylindrical coordinate defined at centre (Graded Mesh).The maximum hoop (tangential) stress is found to be 2.70 MPa.

Plots of pin bearing pressure and the max. tangential stress

Pin bearing stress distribution is shown by screen shot in figure 23. Plots of pin bearing stress / pressure and maximum tangential stress are be obtained from PATRAN shown below.

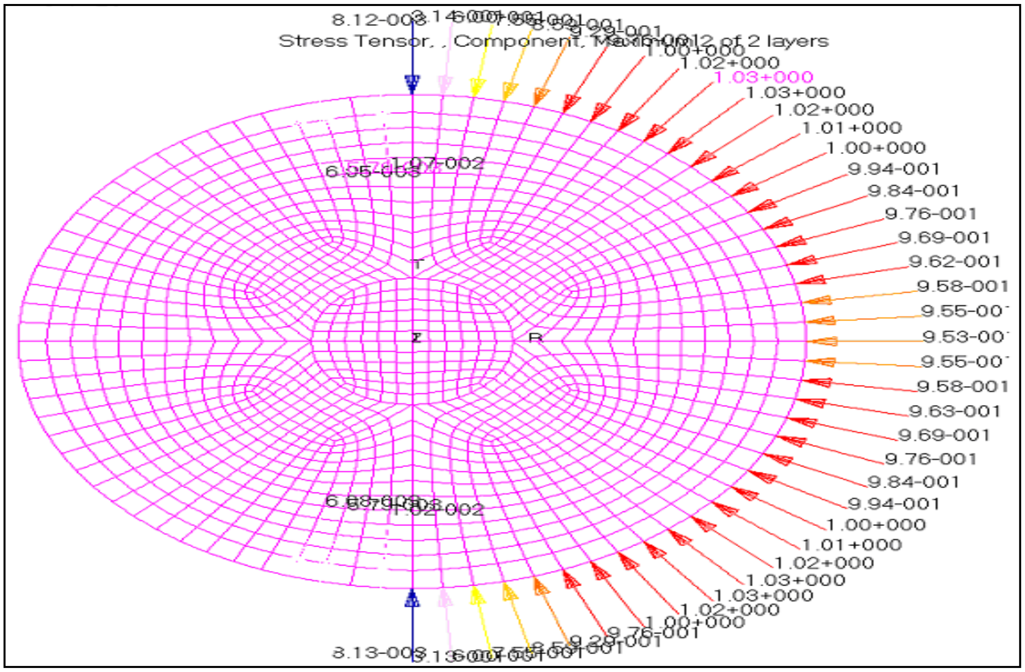


Fig 12:-Plot of pin bearing stress (radial stress shown as vectors)

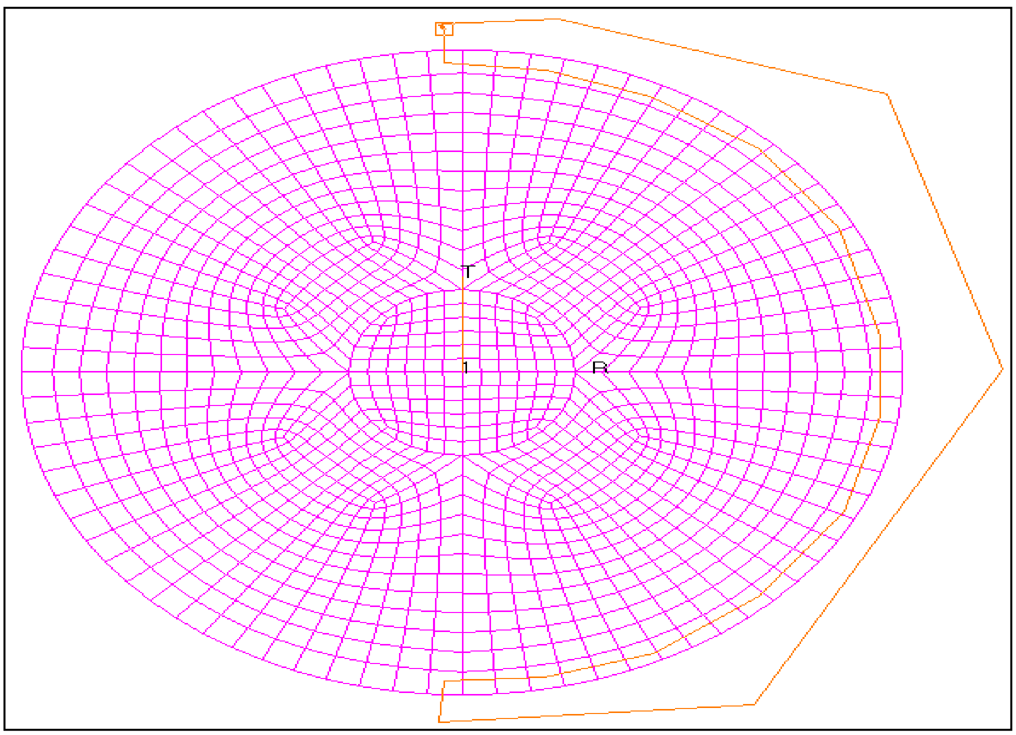


Fig 13:-Selection of nodes on the pin to plot the pin bearing stress

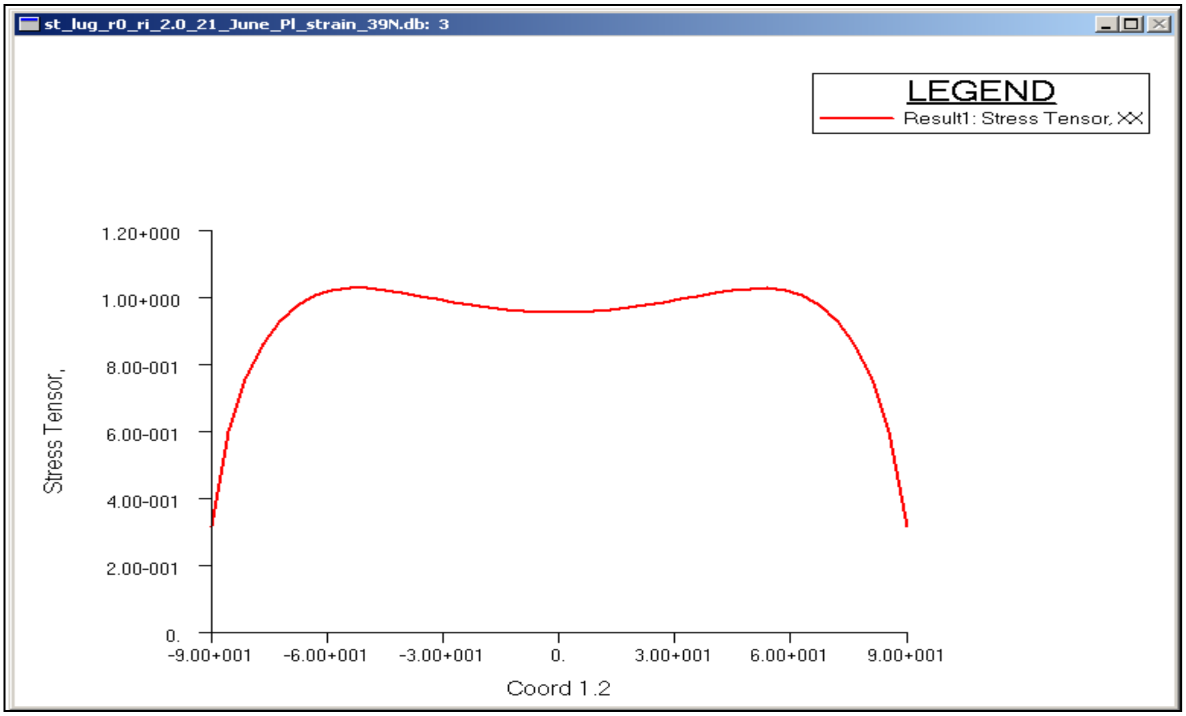


Fig 14:-Plot of pin bearing stress (X component stress in cylindrical coordinate system) vs. θ varying from -90 degrees to +90 degrees on the nodes belonging to the pin boundary.

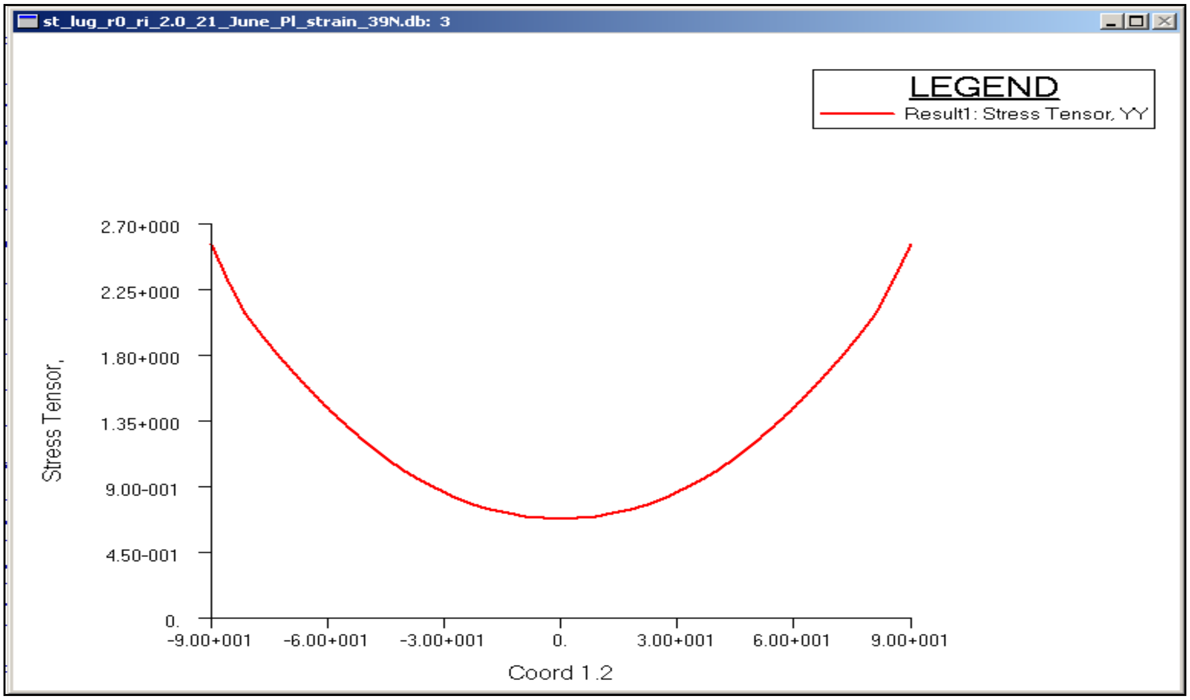


Fig 15:-Plot of max. tangential stress (Y component stress in cylindrical coordinate system) vs. θ varying from -90 degrees to +90 degrees on the nodes belonging to the lug hole boundary.

Calculation of Stress Concentration Factor (SCF)

The maximum local hoop stresses are found from analysis for both the models (Uniform & Graded). The nominal stress here is considered as the bearing stresses that equals to unity[Kathiresan.K et al, 1984].

$\sigma_{bearing} = P / (2*R_i*t) = 39 / (2*19.5*1) = 1$ MPa.

$SCF = \sigma_{max} / \sigma_{bearing}$

Comparison of computed SCFs [1] with Reference

Solution	SCF	% Error
Ref [1]	**2.75**	
Uniform Mesh	**2.69**	**2.18**
Graded Mesh	**2.7**	**1.82**

Table 4:-Stress Concentration Factor Results

The elements near the zone of interest should not fail (< defined default value). It is better to maintain aspect ratio 1.0 for all quad4 elements.

Results & Discussion:-

A finite element model of the Lug joint under constant tensile loading in x-direction was successfully investigated for Stress Concentration Factor, Bearing Stress, Hoop stress and Displacements, and are numerically compiled as shown in the above table, graphs and FEM Contour plots. The present investigation accurately predicts the values of stress distribution at the lug and the pin contacts where the stresses are maximum at 60^o and minimum at 90^o with reference to x-component while the stresses are maximum at 90^o and minimum at 0^o with reference to y-component for a Lug under constant axial loading (Static case).

Conclusions:-

A practically faced problem of a Lug joint was successfully investigated for a straight Lug under an axially loaded condition for which the results obtained has a deviation of 2.18% and 1.82% with respect to the solution obtained in the literature considered for the reference.

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