IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

STUDY OF EFFECT OF RADIAL CLEARANCE ON CLOSE FIT JOINTS ON LOAD TRANSFER CAPABILITY IN DOUBLE SHEAR LAP JOINT

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Abstract: In this study, an analytical approach is used to find the effect of radial clearance between hole and fastener in load transfer capability of double shear lap joint. An undersized bolt shank or oversized hole is a deviation due to the fabrication constraints even in aerospace industry where high precision is needed. This may increase the radial clearance between bolt shank and hole in the connecting members. As a result bending of bolt shank and corresponding change in mechanics from close fit configuration to a loose fit configuration arises. This bending may cause early failure of bolt. To find the maximum allowable clearance for safe load transferring a double shear lap joint is modeled and analyzed using Ansys software by varying bolt hole diameter to find the variation of stress along fastener.

***Index Terms* – Double Shear Lap Joint, Radial Clearance, Shear Bolt, Close Fit, Load Transfer Capability**

1. INTRODUCTION

Bolted joint is the popular method of fastening components together. The prime reason for selecting bolts as opposed to welding or rivets are that the connection can be easily released allowing disassembly, maintenance and inspection. It has a various application for mechanical joint like in aerospace, ship, internal combustion engine, automobile, or oilrig, etc and for civil structure and pipelines. Fastener joints by application can be a tensile joint and shear joint. Tensile joints are mostly likely clearance joints whereas shear joints are close fit or shear fit joints. Close fit joints are used frequently in structural and commercial applications where shear load is dominating over tensile load. They consist of a shear bolt with a close tolerance shank and hole on the joining structures. But it is difficult to maintain the close fit during assembly due to fabrication constraints in high volume manufacturing. An undersized bolt shank or oversized hole is a deviation due to the fabrication constraints even in aerospace industry where high precision is needed. This may increase the radial clearance between bolt shank and hole in the connecting members. As a result bending of bolt shank and corresponding change in mechanics from close fit configuration to a loose fit configuration arises. This bending may cause early failure of bolt or joint. In this paper the effect of radial clearance is studied in detail by finite element analysis for a double shear lap joint.

1.1 Objective of the Project

The change in load transfer capability of the joint and any (probable) change in failure mode scenario is the object of study

2. FINITE ELEMENT ANALYSIS

2.1 Steps for FEA

Finite element analysis (FEA), is a computational technique used to obtain approximate solutions of engineering problems i.e.; to predict the response of structures and materials. Due to the complexity of the structures are usually calculated by numerical methods such as the finite element method. The study will focus on modifying few of above stated parameters to suggest improvements in existing method of fastening. Testing of modified design will be done by using FEM software for stress distribution. FE analysis is widely used to validate the complex designs. The modelling and analysis will be done using Finite Element Analysis software.

In addition it is an efficient design tool by which designers can perform parametric design studies by 29 considering various design cases (different shapes, materials, loads, etc.), analyze them and choose the optimum design .Hence the method has increasingly gained popularity among both researchers and practitioners.

The following steps are involved in this structural analysis.

- Creation of geometry
- Real constants and cross-section properties
- Selection of element type
- Meshing
- Selection of material and properties
- Define loads and displacements
- Reviewing results
- Verify of results

2.2 Finite Element Model

To evaluate the influence of the radial clearance deviation during fabrication, Lap shear test is planned with different diameter of the holes in the plate. Double shear lap joint with shear bolt is designed and analyzed with different radial clearance. A double shear bolted lap joint consists of a bolt, a nut, washers and three plates. Three plates 120mm x 40mm x 5mm made of 15CDV6 and M6 shear bolt assembly are considered for study. The shear bolt failure is anticipated with selection of 15CDV6 steel plates. Finite element model of the double shear lap joint is shown in fig. 1. Solid 186 and contact 174 in Ansys are used for analysis. The Finite Element mode has 518403 nodes and 181381 elements. Finer mesh is used at the hole location and fastener to capture the exact stress distribution. Frictional contact is provided between plates, top plate & shank of fastener, bottom plate & shank of fastener, middle plate and shank, top plate & head and bottom plate & nut with coefficient of friction of 0.2. At one end of the bottom plate and top plate, fixed support is provided to simulate fixity in UTM and a tensile force is given at free end of middle plate to simulate loading in UTM as shown in the fig. 2.

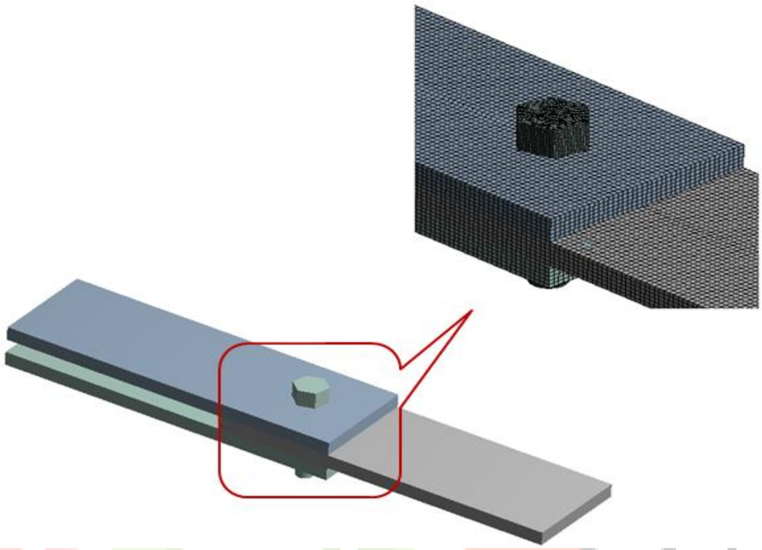

Fig. 1 Finite element model of double shear lap joint

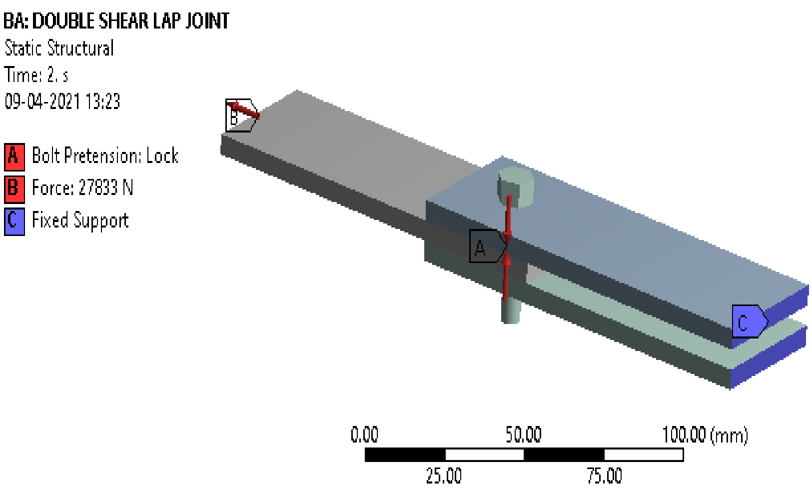

Fig. 2 Loads and boundary condition of double shear lap joint

Pre stress in tensile fastener is 60% of yield strength in the design whereas 30% of yield strength is considered in shear bolts. Preload of 8732N corresponding to 309MPa is applied on the shank of the bolt in the first step of the analysis. The end load of 27833N is applied subsequently. The radial clearance of 0.005mm to 0.05mm is considered for study.

2.2.1 Material properties

Plates are made of High strength steel. M6 hexagonal nut and bolt assembly are made of 1250MPa class steel. Plane washers are made of high strength structural steel. For the sake of analysis metal properties corresponds to structural steel is used for both nut, bolt and washers. The material properties of the materials considered for study is shown in Table 1.

Table 1. Mechanical properties of materials considered for analysis

Materials	Unit	Plate -High Strength Steel (15CDV6)	1250 Class Fastener Steel (35NCD16)
Elastic Modulus	MPa	206010	205800
Poisson's Ratio	--	0.3	0.3
Shear Modulus	MPa	79235	79154
Density	kg/m^3	7800	8000
Yield Strength	MPa	835	1030
Ultimate Strength	MPa	981	1250

3. RESULTS AND DISCUSSIONS

Maximum principal stress in top plate, middle plate and bottom plate is shown in fig. 3 to fig.4 respectively.

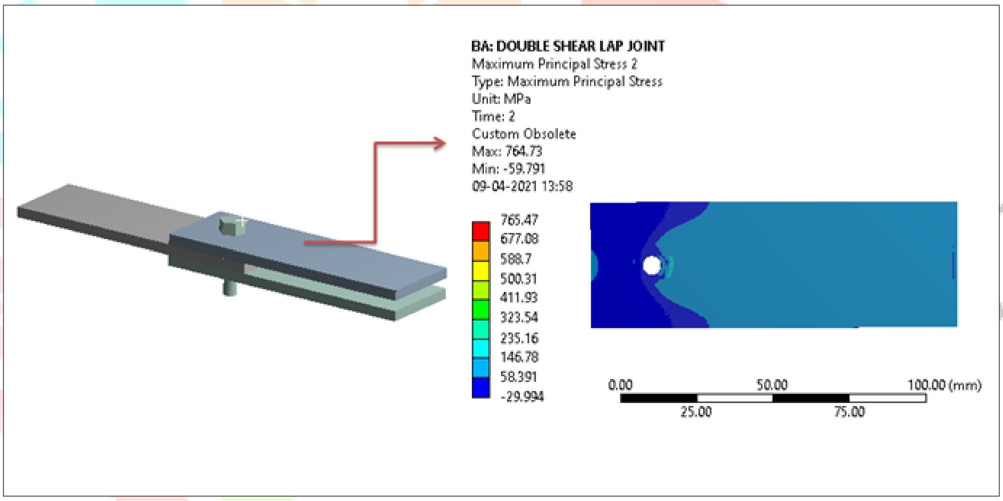

Fig. 3 Maximum principal stress in top plate

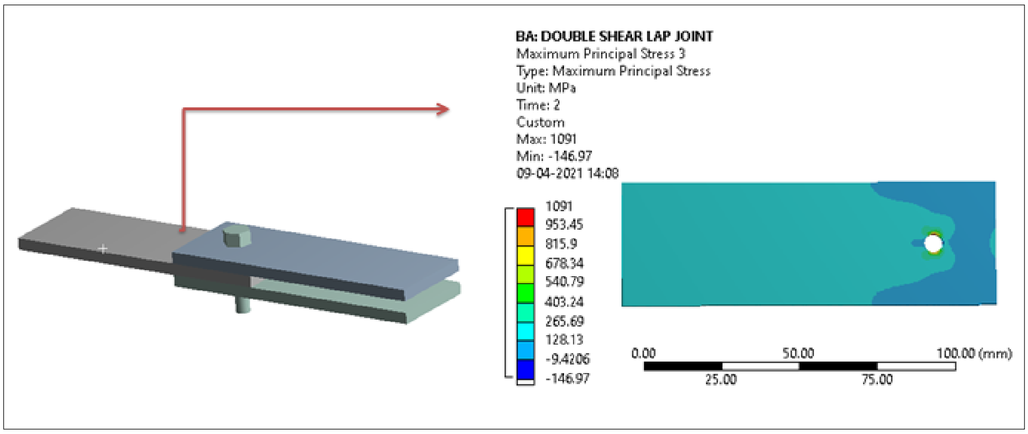

Fig. 4 Maximum principal stress in middle plate

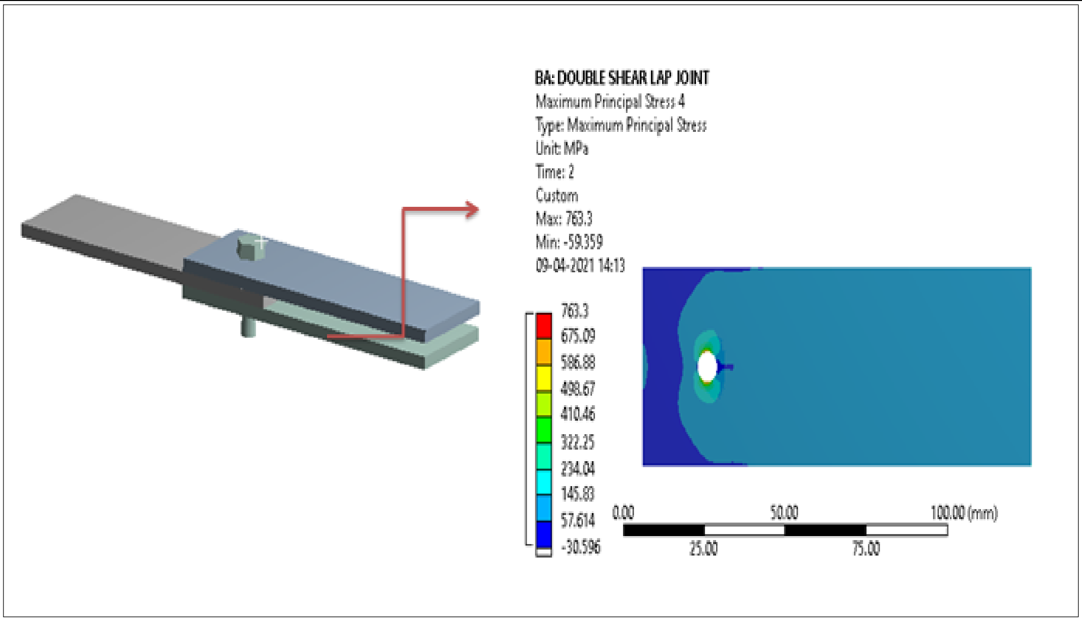

Fig. 5 Maximum principal stress in bottom plate

It can be seen that the maximum principal stress is 765.47MPa at the top plate and 763.83MPa at bottom plate.

3.1 Fastener Stress

Pre stress and final fastener stress are shown in figure 6. Pre stress simulated in the fastener is 308.2MPa and is same in the load step 2 also. Stresses in the fastener at the middle location of the bottom plate & at the middle location of the top plate and middle location of middle plate are plotted. Maximum, average stress at t/2 of bottom plate, top plate, and middle plate is given in fig. 7 to fig. 9 respectively.

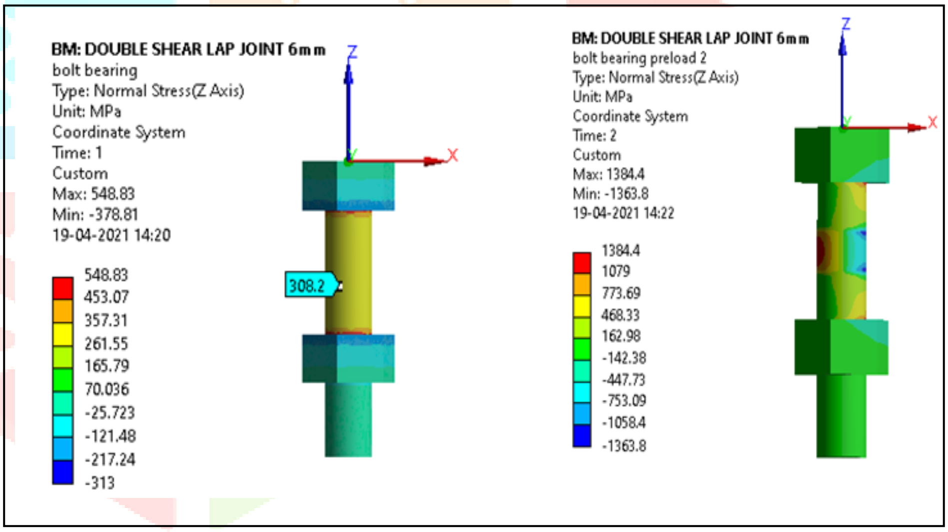

Fig. 6 Pre stress and final fastener stress

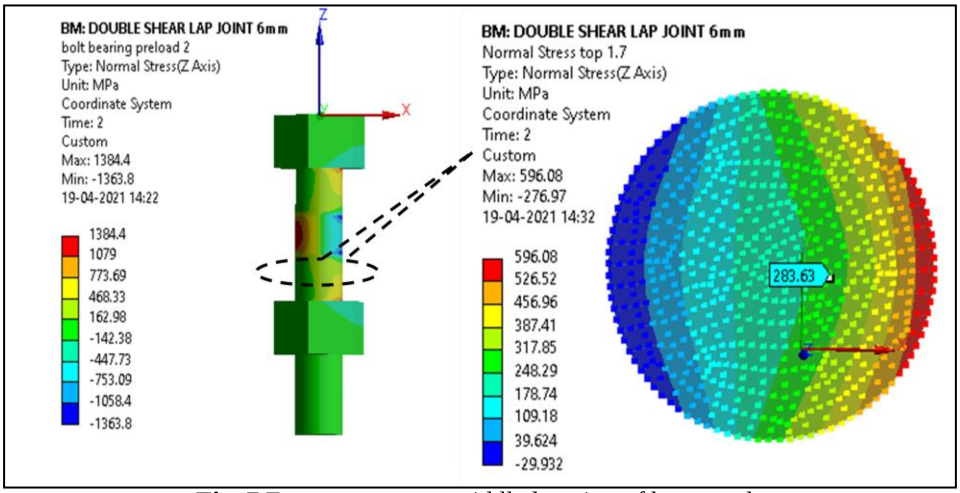

Fig. 7 Fastener stress at middle location of bottom plate

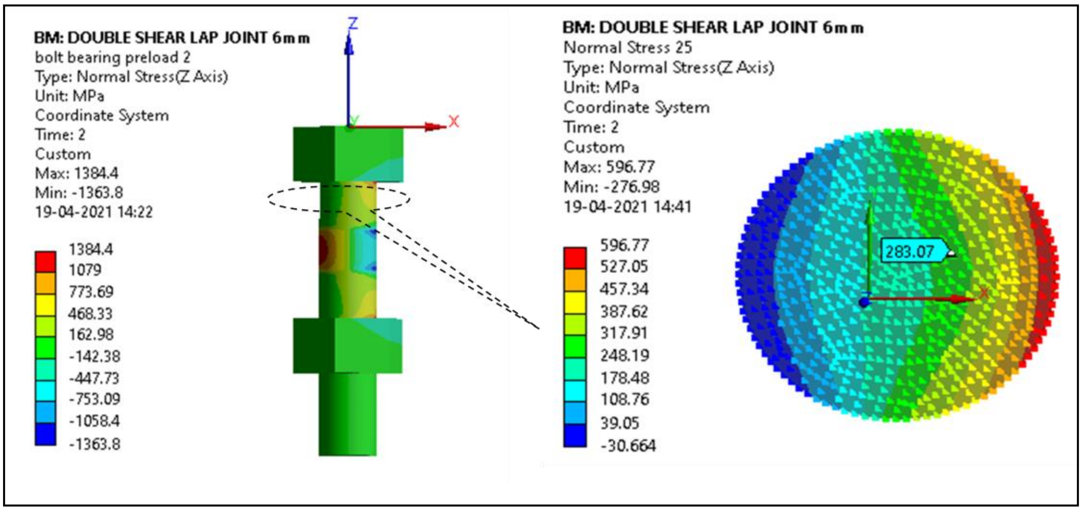

Fig. 8 Fastener stress at middle location of top plate

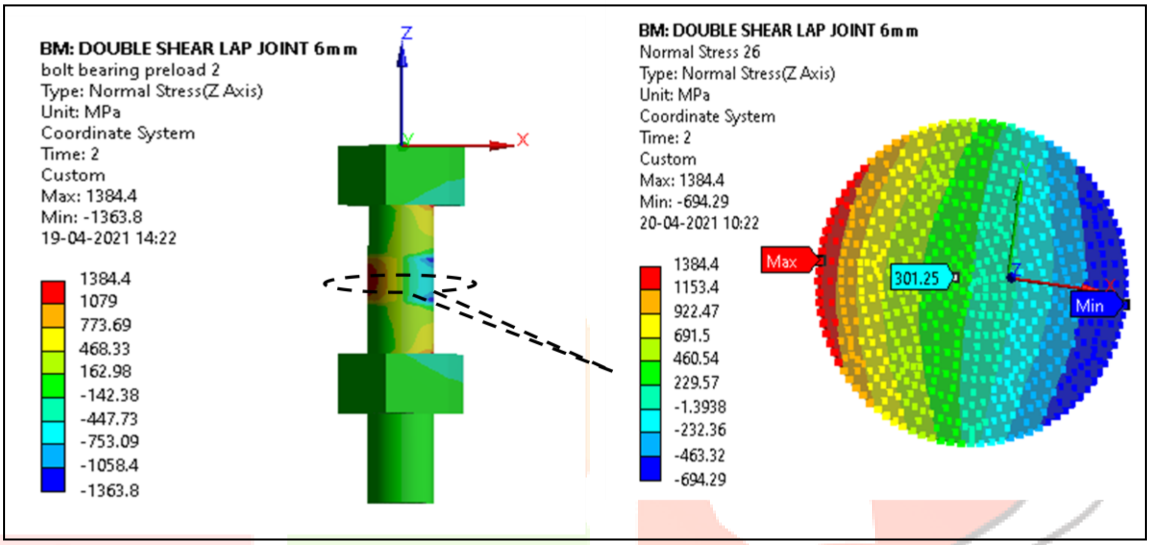

Fig. 9 Fastener stress at middle location of middle plate

It can be seen that the average stress at t/2 is 283MPa in both top plate and bottom plate which is same as the preload provided. The average stress at t/2 of middle plate is 301MPa which is close to preload applied.

3.2 Stresses in Plates with Clearance

Maximum principal stress in top plate and bottom plate with clearance is shown in fig. 10 and fig.11 respectively. From fig. 11, it can be seen that maximum principal stress in bottom plate is reduced to 697.62MPa from 763.3MPa (ref fig. 5) due to the effect of clearance.

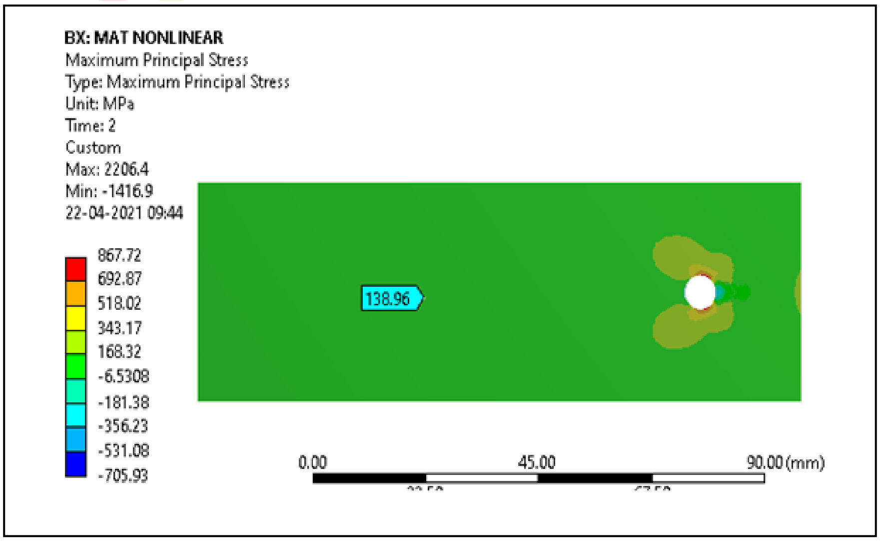

Fig. 10 Maximum principal stress in top plate

It can be seen from figure 10 the maximum principal stress is increased to 867.72MPa from 765MPa (ref fig. 3) due to the effect of clearance.

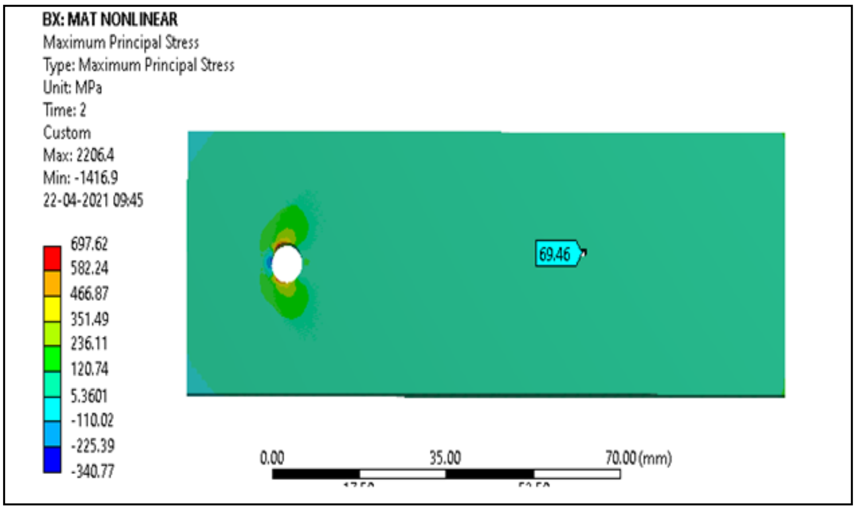

Fig. 11 Maximum principal stress in bottom plate

3.3 Variation of Fastener Stress due to Clearance

Analysis is carried with different hole diameters varying from 6.00 mm to 6.3mm which simulated the higher radial clearance between the bolt and hole. Variation in Fastener stress due to different radial clearance from 6.00 mm to 6.3mm are tabulated at 0°and 180° and are given in Tables 2 & 3 respectively. Variation of stress in fastener due to change in bolt hole clearance plotted at the middle location of the middle plate is shown in chart - 1. Variation of stress in fastener with respect to radial clearance also plotted and is shown in chart- 2.

Table 2 Stress due to different radial clearance from 6.00 mm to 6.3mm at 0°

Hole dia.(mm)	Radial clearance (%)	Stress (MPa) at different distance along bolt axis from one end				
		2.5	5	7.5	10	12.5
6	0.00	-19.571	213.82	1379.1	213.98	-20.298
6.01	0.17	-38.176	194.16	1379.1	194.51	-37.746
6.02	0.33	-56.043	177.7	1390.8	177.84	-56.045
6.03	0.50	-78.281	176.93	1396.8	179.39	-78.086
6.04	0.67	-89.889	154.55	1404.1	153.97	-90.251
6.05	0.83	-102.01	150.42	1405	150.85	-102.19
6.1	1.67	-167.33	108.05	1438.9	107.73	-167.66
6.2	3.33	-268.17	63.416	1467.6	63.562	-268.03
6.3	5.00	-335.11	-117.71	1424.4	-112.27	-340.55

Table 3 Stress due to different radial clearance from 6.00 mm to 6.3mm at 180°

Hole dia.(mm)	Radial clearance (%)	Stress (MPa) at different distance along bolt axis from one end				
		2.5	5	7.5	10	12.5
6	0.00	577.95	-576.8	-689.76	-577.2	578.61
6.01	0.17	574.68	-590.93	-698.79	-590.89	574.38
6.02	0.33	579.17	-602.32	-717.28	-603.17	579.35
6.03	0.50	583.33	-625.8	-731.91	-625.49	582.94
6.04	0.67	586.41	-631.44	-749.2	-632.38	587.00
6.05	0.83	589.27	-641.72	-757.23	-642.31	589.54
6.1	1.67	599.5	-697.3	-870.94	-698.15	599.68
6.2	3.33	615.34	-733.12	-1061	-733.98	615.67
6.3	5.00	614.85	-850.25	-1181.7	-873.83	602.10

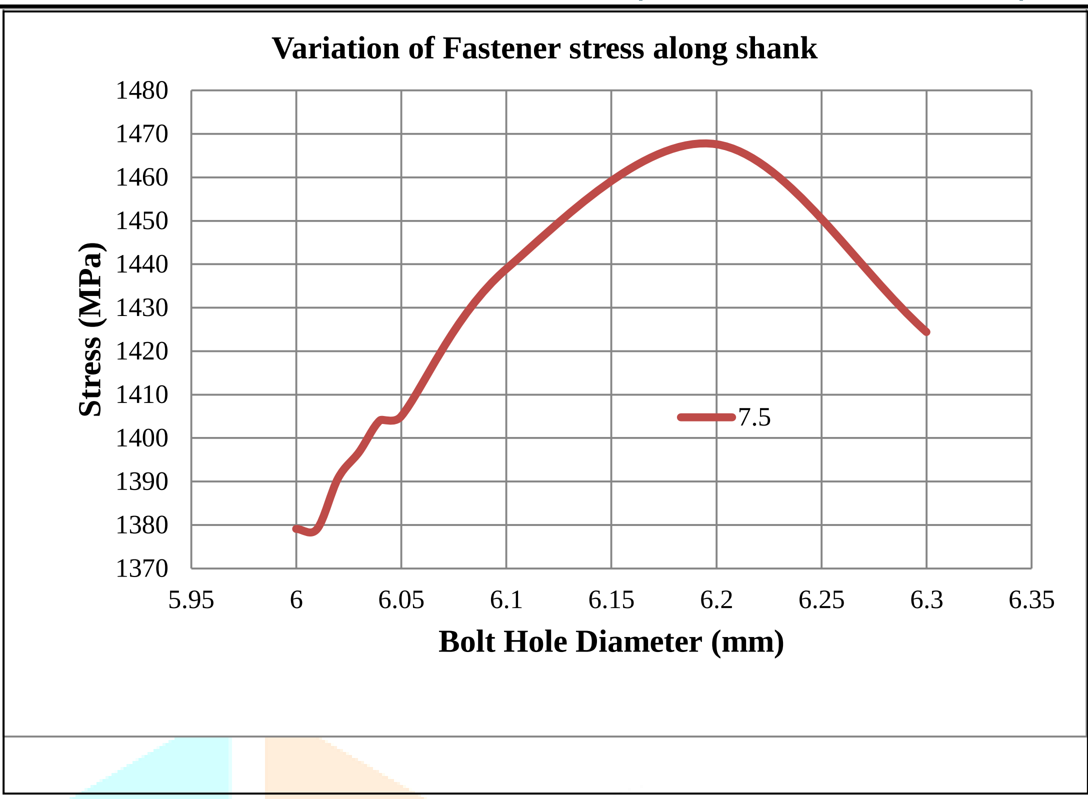

Chart - 1 Maximum principal stress in bottom plate

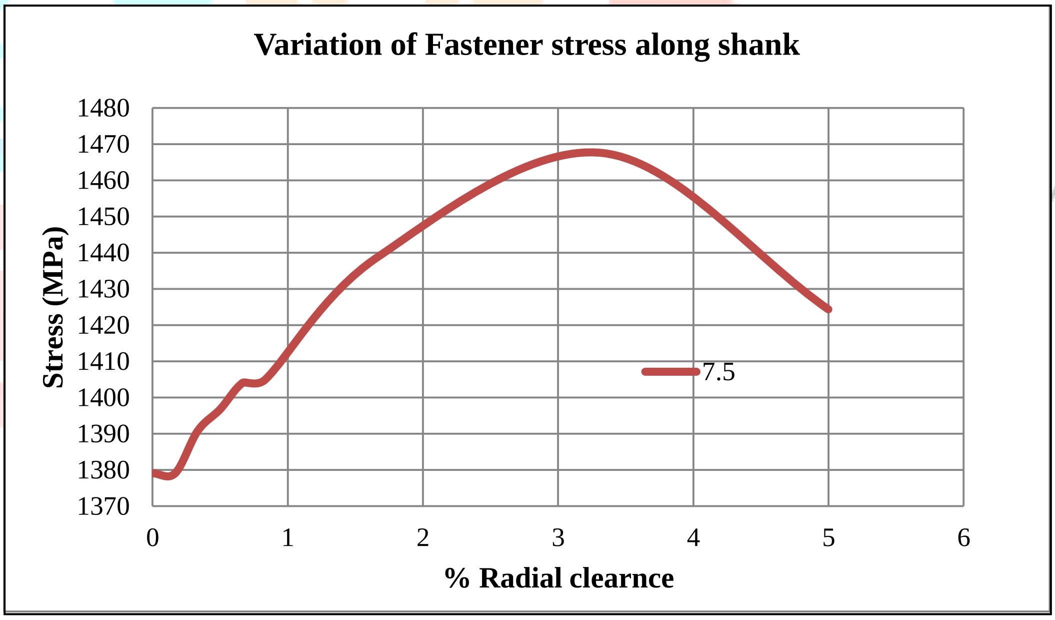

Chart - 2 Variation of stress along shank with % radial clearance

It can be seen that the stress in the shank is reduced at the middle for radial clearance beyond 0.1mm (3.1-3mm). This indicates that the load carrying capability of the joint is reducing beyond the radial clearance of 0.1mm. The radial clearance of 0.1 mm corresponds to 3.33% and beyond this the bending stress is reduced. It can be concluded that the radial clearance deviation permitted for structural elements with two cover plate is 3.33% .

4. CONCLUSIONS

In this study, an analytical approach is used to find the effect of radial clearance between hole and fastener in load transfer capability of joints. An undersized bolt shank or oversized hole is a deviation due to the fabrication constraints even in aerospace industry where high precision is needed. This may increase the radial clearance between bolt shank and hole in the connecting members. As a result bending of bolt shank and corresponding change in mechanics from close fit configuration to a loose fit configuration arises. This bending may cause early failure of bolt. To find the maximum allowable clearance for safe load transferring a double shear lap joint is modeled and analyzed using Ansys software by varying bolt hole diameter to find the variation of stress along fastener.

From the analysis it is obtained that stress in the shank is reduced at the middle for radial clearance beyond 0.1mm (3.1-3mm). This indicates that the load carrying capability of the joint is reducing beyond the radial clearance of 0.1mm. The radial clearance of 0.1 mm corresponds to 3.33% and beyond this the bending stress is reduced. It can be concluded that the radial clearance deviation permitted for structural elements with two cover plate is 3.33%.

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