Assessment of Effectiveness of Fasteners for the Structural Performance of a Joint by using FEA

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Abstract— Bolted joints are generally used in industries like automobiles, machines, structures and so on. The design of joint is as important as machine components because a weak joint may spoil the utility of a carefully designed machine part. So it is becoming increasingly important to accurately predict the behaviour of bolted joints. The research is presented with variants of different array patterns proposed for the shear strength investigation of bolted joint to be used in the industry. The problem is assessed by using Finite Element Analysis and validated by experimental testing. Finite Element Analysis tools and techniques are being used for stress analysis in bolts to connect test piece in different array pattern. Experimental work was carried out and test piece of bolted connection was tested to validate the results obtained in FEA.

Key words: FEA, Stress analysis, Shear stress, Bolted joint

I. Introduction

Often small machine components are joined together to form a larger machine part i.e; an assembly. The whole product is broken down into elements to facilitate manufacturing and dis-assembly for simplicity of maintenance or replacement. Most products are made from more than one piece of material, so when the product is assembled or fabricated the pieces needs to be joined. The decision to be made in this case pertains to the type of joint to be used. Joints between materials can be temporary or permanent. Permanent joints cannot be dissembled without damaging the components. They make use of adhesives, nails, rivets, or one of the heat processes of brazing, soldering or welding. Non-permanent joints can be assembled and dissembled without damaging the components. Example of such joints are threaded fasteners (screw joints), keys and couplings etc. The temporary or non-permanent joint can be also as strong- but it is a type which can be modified according to the alteration required. The parts which can be easily dismantled and assembled, making it easy to transport. The effectiveness i.e., strength of the joint could be varied by locating the joint in the optimum place and by choosing the optimum method to join the same.

Threaded Fasteners are one of the most critical components in a mechanical assembly, and in most industrial rotating machinery. It is possible that bolt will predominate as the most effective means of joining in future machines due to ease of assemble and disassemble and compactness.. Failures in the bolts can be minimized by careful analysis of the problem during the design stage and assigning proper number of bolt requirement and selecting proper dimensions for bolt and nut with proper joining configuration. In this thesis, analysis of the different joining configuration of threaded fasteners was studied using linear FEM. The vast use of threaded fastener in machines, vehicles, elevators etc, has created a growing demand for a more precise analysis of the characteristics of fastener.

II. Finite Element Analysis

The finite element analysis (FEA) tools and techniques used to obtain approximate solutions of boundary value problems in engineering. Due to the complexity in the structures, stresses are calculated by numerical methods such as the finite element method. The finite element analysis (FEA) is used for finding approximate solutions of partial differential equations (PDE) as well as of integral equations. The solution approach is based either on eliminating the differential equation completely, or converting the PDE into an approximating system of ordinary differential equations, which are then numerically integrated.

The power of finite element analysis is now apparent since these predictions can be made at any point in the structure. Furthermore, the complex geometry of the bolted joint can be accurately described by the element mesh so the variation in geometrical features, such as the orientation of bolted connection in circular and rectangular pattern, on joint performance is accounted for in the analysis. This is particularly important in the design of bolted joints because these features are usually associated with regions of stress and strain concentration at which joint failure will generally initiate. From the above, it is clearly possible to determine the strength of the joint. This prediction involves the generation of small strains in the bolts and a stress analysis is satisfactory with suitable variant for the bolted connection. Finding FEA solution of engineering problems, such as deflections and stresses in a structure, requires three steps:

1) Pre-process or modeling the structure
2) Analysis
3) Post processing

A. Stages of Analysis

1) 3D Modeling in CATIA

The three dimensional model of bolted joint of circular array pattern and rectangular array pattern is prepared in CATIA V5 R16 environment. For analysis, 3D model is created with the help of CATIA software. Model of each geometry in three dimensions views and that will help to visualize properly and to clear idea about model quickly.

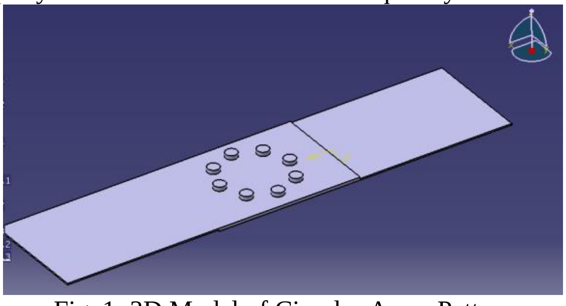

Fig. 1: 3D Model of Circular Array Pattern

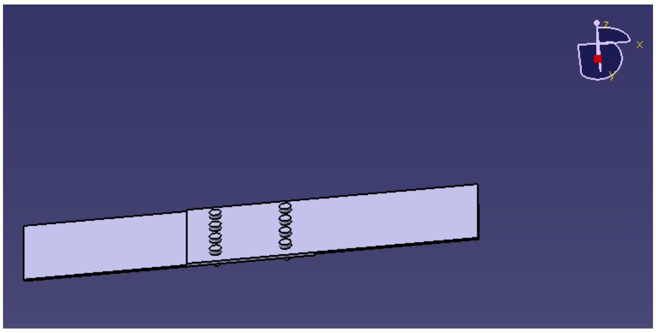
Fig. 2: 3D Model of Rectangular Array Pattern

2) Meshing Of Geometry Using FEA Software (ANSYS)

Fine meshing gives an accurate stress distribution in a reasonable analysis time. The finer mesh gives optimal solution is in areas of high stress, i.e; in the contact zones of the joint, then in the remaining areas. In order to simplify the model, hexagonal bolt head and nuts are created as circular and washers are not modeled. Bolts holes are assumed to be equal with bolt size. Finite element software (ANSYS) is used for stress analysis. The elements used in plate assembly model are first order Hexa and Penta elements. Finite element models for stress analysis are consisted of 48794 elements and 274244 nodes each for both circular and rectangular array configuration as shown in Fig. 3 and 4 respectively. Bolt joint model has been meshed by first order Hexa and Penta elements. Element type used is SOLID 185.

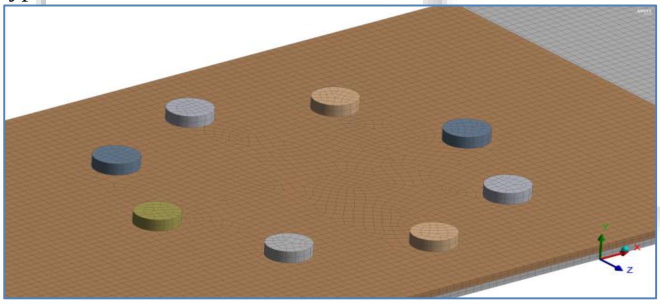
Fig. 3: Meshing of Circular Array Pattern

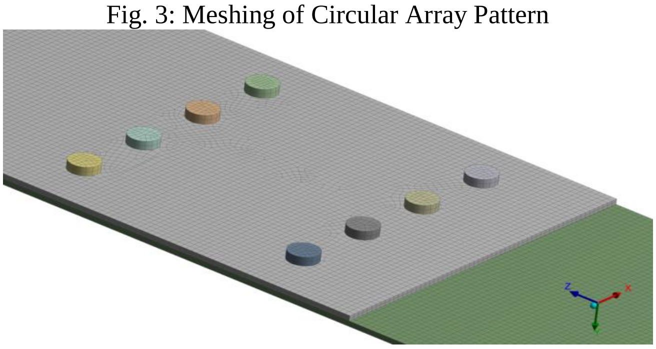
Fig. 4: Meshing of Rectangular Array Pattern

3) Materials and Method

After meshing (Discretisation) of geometric model, the material is specified for both plate and nut-bolts. Two material models were used in this model, one for the plate elements, and the other for the nut-bolts. The material for the plate is considered as hot rolled steel (HR) and the yield stress considered for the plate is 340 MPa The material of bolt used is EN8 grade steel having its yield stress 950 MPa, poisson's ratio 0.3, modulus of elasticity 205*10^9Pa.

4) Load Application and Boundary Conditions

The loading condition is specified in ANSYS software. Main focus of this thesis is on the stress analysis of threaded fastener (Bolt) under shear loading. Hence end of plate-A is constrained (fixed) by keeping DOF zero for all nodes at the end surface of plate-A. Then a force of 1000 to 5000 N is applied gradually at the right end face of Plate-B in X-direction which acts as tensile force as shown in fig.5 and fig.6.

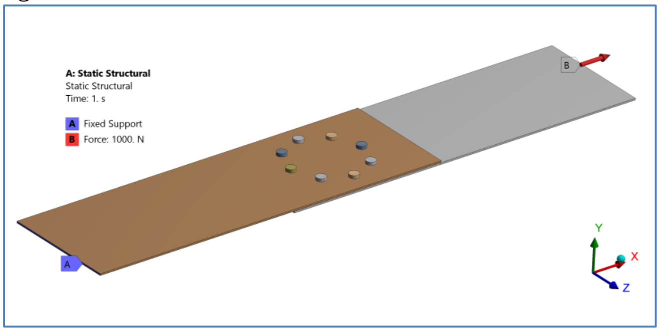

Fig. 5: Loading Condition of Circular Array Pattern

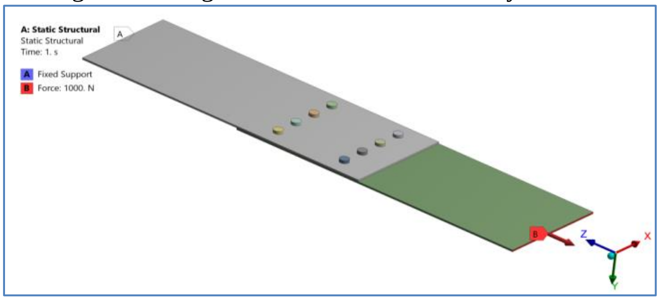

Fig. 6: Loading Condition of Rectangular Pattern

a) FEA of M10 Bolt in Circular Array Pattern

Two plates of dimension 500 x 180 x 3 mm are connected together by eight number of M10 x 1.5 x 25 mm bolts in circular array pattern placed over the of PCD of 120mm and overlapping length of plates is 241mm as shown in fig.1. Tensile Load has to be applied at one end of the plate and keeping the opposite plate end fixed. Tensile load of 1000 to 5000 N is applied gradually in order to determine the maximum equivalent stress induced in bolts for circular array pattern. 3-D geometrical model is prepared on CATIA-V5 software for plates connected with eight number of bolts in circular array pattern which is further exported for finite element stress analysis under certain loading condition in FEA software.

After application of load the finite element model is solved in ANSYS for the stress results. As the tensile force of 1000-5000 N is applied in X-direction, the maximum value of equivalent stress component observed is 109.84 MPa. This is less than the yield strength of the bolt material. The stress values obtained in finite element analysis of M10 circular array pattern is shown in table 1 and the contour plot of displacement plot and stress distribution for component i.e. equivalent stress is shown in fig. 7 & 8 respectively.

Load (N)	Equi. stress (MPa)	Displacement (mm)
1000	21.551	0.24587
2000	43.308	0.49172
3000	65.274	0.73755
4000	87.45	0.98334
5000	109.84	1.2291

Table 1: Stress results for M10- Circular Array

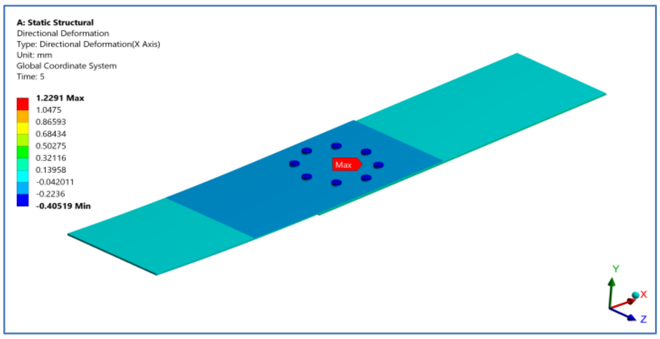

Fig. 7: Displacement Plot

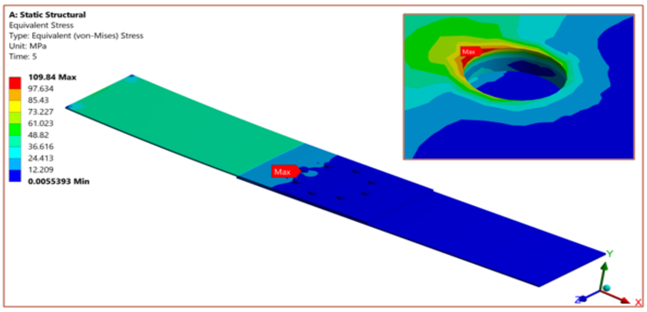

Fig. 8: Equivalent Stress Distribution

b) FEA of M10 Bolt in Rectangular Array Pattern

Two plates having dimension 500 x 180 x 3 mm are connected together by eight number of M10 x 1.5 x 25 mm bolts in rectangular array pattern with column offset of 120 mm and row offset of 40 mm and overlapping length of plates 220 mm as shown in fig.2. Tensile Load has to be applied at one end of the plate and keeping the opposite plate end fixed. Tensile load of 1000-5000N is applied in order to determine the shear stress induced in bolts for rectangular array pattern. 3-D geometrical model is prepared on CATIA-V5 software for plates connected with eight number of bolts in rectangular array pattern as shown in fig.2 respectively. 3-D model is exported for finite element stress analysis under certain loading condition in FEA software.

After application of load the finite element model is solved in ANSYS for the stress results. As the tensile force of 1000-5000 N is applied in Z-direction, the maximum value of equivalent stress component observed is 78.033 MPa. This is substantially less than the yield strength of the bolt material. The stress values obtained in finite element analysis of M10 rectangular array pattern is shown in table-2 and the contour plot of displacement plot and stress distribution for component i.e. equivalent stress is shown in fig.9 & 10 respectively.

Load (N)	Equi. Stress (MPa)	Displacement (mm)
1000	15.811	0.15311
2000	31.52	0.3062
3000	47.126	0.45928
4000	62.63	0.61233
5000	78.033	0.76537

Table 2: Stress results for M10- Rectangular Array

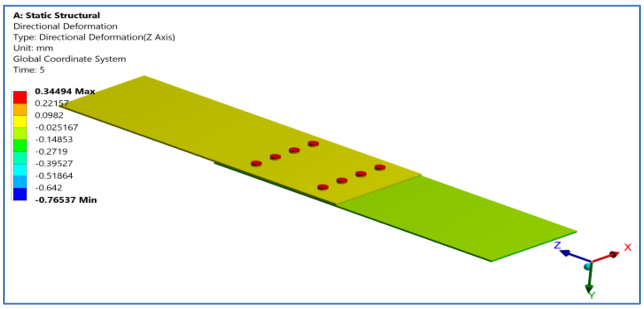

Fig. 9: Displacement Plot

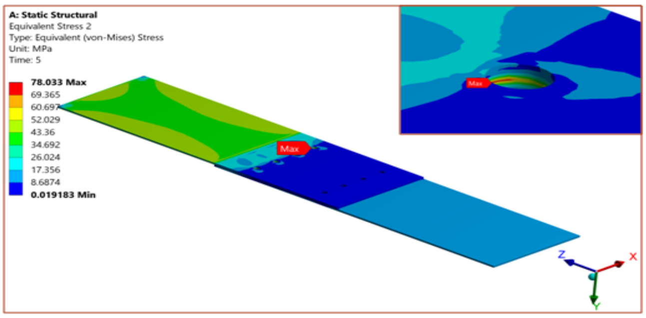

Fig. 10: Equivalent Stress Distribution

5) Result and Discussion

From the above results we can see that the maximum value of equivalent stress observed in bolts connected in rectangular array pattern (78.033 MPa) is less than in circular array pattern (109.84 MPa). This FEM analysis shows that for connection of two members with threaded fastener, the rectangular array pattern is more effective than connecting same members with circular array pattern by keeping number of bolts same. Along with that we can also see that value of maximum displacement of bolt in circular array pattern bolt is more (1.2291mm) than that of rectangular array pattern (0.765mm) as shown in fig. 7 and fig. 9 respectively.

6) Concluding Remarks

In both pattern the maximum stress induced in bolts is within the limit. Means stresses induced in the bolts for both array patterns are less than the yield strength of bolt material which is 950 MPa.

So, here is a scope to use the small diameter bolts to connect the same plates. Hence for the same material and dimensions of plates M8 x 1.25 x 25 mm size bolts are used to connect the two plates in both circular and rectangular array pattern and the model is analysed for stress analysis under the same loading conditions by following the same procedure which is followed for previous analysis of M10 bolt, keeping the bolt material and applied load same.

a) FEA of M8 bolts in Circular Array Pattern

Two plates having dimension 500 x 180 x 3 mm are connected together with M8 x 1.25 x 25 mm bolt keeping number of bolts eight in circular array fashion with of PCD as 120mm and overlapping length of 241 mm as shown in fig-1. Tensile load of 1000-5000 N has to apply gradually in order to determine the shear stress induced in bolts for circular array pattern.

The maximum stresses are observed in bolt at shank region just beneath the bolt head. The maximum value of stress component i.e; equivalent stress observed is 113.56 MPa. This is again less than the yield strength of the bolt material. The stress values obtained in finite element analysis of M8 circular array pattern is shown in Table-3 and contour plot of the displacement distribution & stress distribution for stress component i.e. equivalent stress is shown in fig. 11 & 12 respectively.

Load (N)	Equi. stress (MPa)	Displacement (mm)
1000	22.287	0.25164
2000	44.784	0.50325
3000	67.493	0.75483
4000	90.417	1.0064
5000	113.56	1.2579

Table 3: Stress results for M8 - Circular Array Pattern

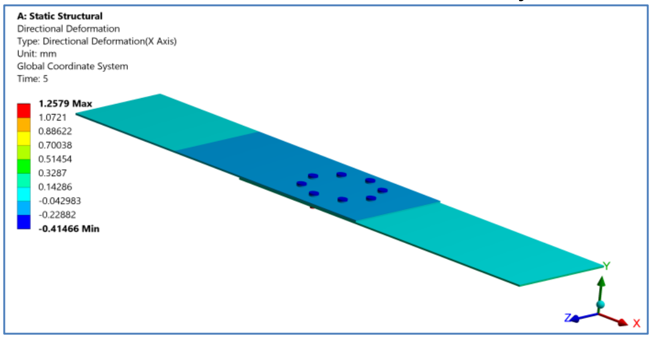

Fig. 11: Displacement Plot

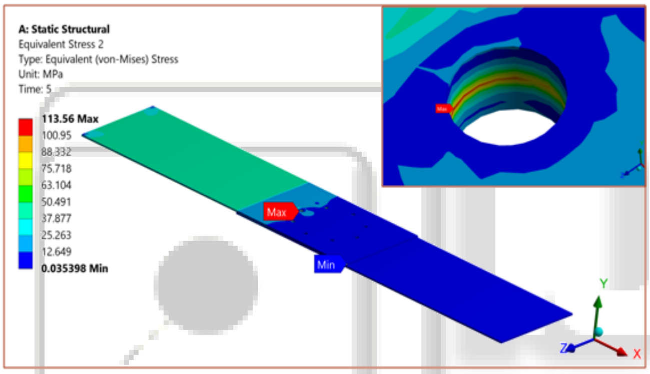

Fig. 12: Equivalent Stress Distribution

b) FEA of M8 bolts in Rectangular Array Pattern

Two plates having dimension 500 x 180 x 3 mm are connected together by eight number of M8 x 1.25 x 25 mm bolts in rectangular array fashion with column offset of 120 mm and row offset of 40 mm and overlapping length of plates 220 mm as shown in fig-2. Tensile Load has to be applied at one end of the plate and keeping the opposite plate end fixed. Tensile load of 1000-5000 N has to apply gradually in order to determine the shear stress induced in bolts for rectangular array pattern and the maximum value of equivalent stress component observed is 99.653 MPa. This is substantially less than the yield strength of the bolt material. The stress values obtained in finite element analysis of M8 rectangular array pattern is shown in table-4 and the contour plot of displacement plot and stress distribution for component i.e. equivalent stress is shown in fig.13 & 14 respectively.

Load (N)	Equi. stress (MPa)	Displacement (mm)
1000	20.153	0.1538
2000	40.194	0.30759
3000	60.124	0.46136
4000	79.943	0.61511
5000	99.653	0.76884

Table 4: Stress results for M8-Rectangular Array

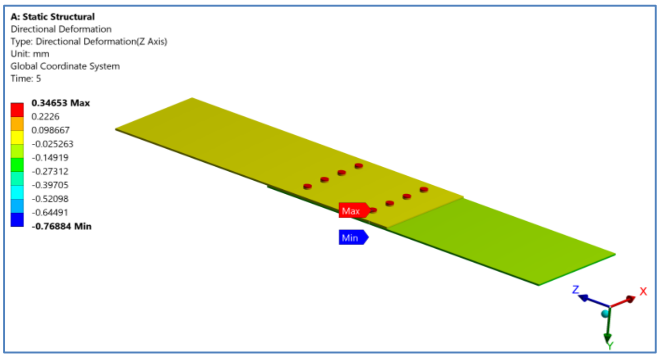

Fig. 13: Displacement Plot

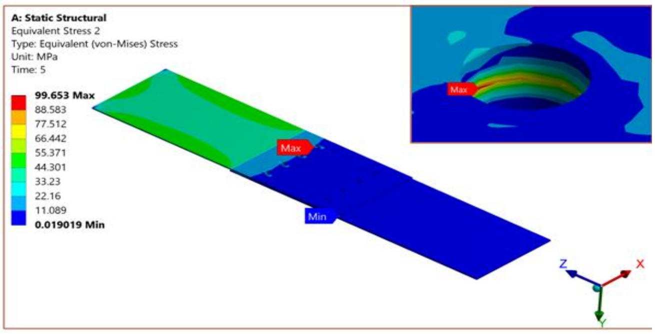

Fig. 14: Equivalent Stress Distribution

From the above results we can see that the value of maximum equivalent stress observed in bolts connected in rectangular array pattern is 99.653 MPa and in circular array pattern is 113.56 MPa. This FEM analysis shows that for connection of two members with threaded fastener, the rectangular array pattern is more effective than connecting same members with circular array pattern by keeping number of bolts same. Along with that we can also see that value of maximum displacement of bolt in circular array pattern bolt is more (1.2579mm) than that of rectangular array pattern (0.768mm) as shown in fig.11 and fig.13 respectively. Results obtained from analytical analysis are as follows:

Stress Component →	Equivalent stress (MPa)	Displacement (mm)
M10- Circular Array	109.84	1.2291
M10- Rectangular Array	78.033	0.76537

Table 5: Results for M10 Bolts

Stress Component →	Equivalent stress(MPa)	Displacement (mm)
M8- Circular Array	113.56	1.2579
M8- Rectangular Array	99.653	0.76884

Table 6: Results for M8 Bolts

7) Concluding Remarks

In both pattern the maximum stress induced in bolts is within the limit. Means stresses induced in the M8 bolts for both array patterns are also less than the yield strength of bolt material which is 950 MPa. Hence for the same material and dimensions of plates, M8 x 1.25 x 25 mm size bolts can be used to connect the two plates in both circular and rectangular array pattern.

III. EXPERIMENTAL ANALYSIS

Result of stresses observed in finite element analysis validated by experimental testing, Experimentation has done on M8 circular array pattern bolt. Two plates of HR steel material are taken as specimen .The eight numbers of holes drilled in circular array with PCD of 120 mm and overlapping length of 241 mm. These plates are then bolted together with M8 X 1.25 X 25 mm hexagonal headed bolts and nuts of carbon steel material by applying the sufficient torque required for tightening. Fig.15 shows the test piece is loaded on UTM. Strain gauge with data logger is used and it is located at region as per the result of finite element analysis i.e. in proximity of bolt region. The test is conducted at a rate of 10 mm /min. Testing is done within the yield limit of bolt material.

Fig. 15: Test piece under test

Load applied (N)	Shear stress by Experimental analysis (MPa)
1000	20.927
2000	41.502
3000	62.124
4000	85.986
5000	108.7

Table 7: Experimental Results

Load applied (N)	Shear stress by Analytical analysis (MPa)	Shear stress by Experimental Analysis (MPa)
1000	22.287	20.927
2000	44.784	41.502
3000	67.493	62.124
4000	90.417	85.986
5000	113.56	108.7

Table 8: Comparative shear stress values of Analytical, Experimental Analysis

IV. RESULTS AND CONCLUSION

Stress analysis of bolted joint using Finite Element Method is carried out with many different types of variants and satisfactory results are achieved. From above results, it is concluded that even by changing the orientation of bolts (i.e. Circular array and rectangular array configuration), stresses induced in both the specimens are within the yield limit of the material. So there is scope to find out more optimised pattern (Square, Diamond etc.) to connect the two plates with threaded fastener. It is also concluded that even by reducing the size of bolts, stresses induced in both the specimens are within the yield limit of the material. Hence, instead of connecting the two HR plates with the help of eight number of M10x1.5x25 mm bolts, we can use same number of M8x1.25x25 mm bolts for the same loading conditions, as the maximum shear stress produced is sufficiently less than the permissible limit.

Further there is scope to reduce the number of bolts from eight to six for the same loading conditions, as the maximum shear stress produced is sufficiently less than the permissible limit.

REFERENCES

[1] "Finite element analysis and modeling of structure with bolted joints", Jeong Kim, Joo-Cheol Yoon, Beom-Soo Kang.
[2] "3D Finite Element Modeling Of Single-Lap Shear Bolted Joints", Alex Selvarathinam, James Frailey, Jim Eisenmann, Lockheed Martin Aeronautics, Cae Development And Support, Lockheed Martin Aeronautics (Retired), International Congress Of The Aeronautical Sciences, 2010.
[3] "Stress Analysis of Bolted Joint", Rashtrapal B. Teltumade, Prof. Y. L. Yenarkar, International Journal of Engineering Research & Technology (IJERT), September – 2013 edition, Vol. 2 Issue 9, ISSN: 2278-0181.
[4] "Effect of Circular Bolt Pattern on Behavior of Extended End-Plate Connection", Roozbeh Kiamanesh, M.ASCE; Ali Abolmaali, M.ASCE and Mohammad Razavi, M.ASCE, journal of structural engineering©asce / november 2013.
[5] "Structural Behavior of Large-Scale Triangular and Trapezoidal Threaded Steel Tie Rods in Assembly Using Finite Element Analysis", Wei Duan, Suraj Joshi, Engineering Failure Analysis 34 (2013) 150–165.
[6] "Rotational stiffness of a blind-bolted connection to concrete-filled tubes using modified Hollo- bolt", Walid Tizani, Ali Al-Mughairi, John S. Owen, Theodoros Pitrakkos, Journal of Constructional Steel Research 80 (2013) 317–331.
[7] "Numerical study of the tensile behaviour of threaded steel fasteners at elevated rates of strain", H. Fransplass, M. Langseth, O.S. Hopperstad, International Journal of Impact Engineering 54 (2013) 19-30.
[8] "Failure analysis and optimization of thermo-mechanical process parameters of titanium alloy (Ti–6Al–4V) fasteners for aerospace applications", Vartha Venkateswarlu, Debashish Tripathy, K. Rajagopal, K. Thomas Tharian, P.V. Venkitakrishnan, Case Studies in Engineering Failure Analysis 1 (2013) 49–60.
[9] "Failure analysis of maraging steel fasteners used in nozzle assembly of solid propulsion system", Abhay K. Jha, M. Swathi Kiranmayee, Sushant K. Manwatkar Engineering Failure Analysis 27 (2013) 308–313.
[10] "Fastener effects on mechanical behaviors of double-lap composite joints", Tianliang Qin Composite Structures 100 (2013) 413–423.
[11] "A global Bolted Joint Model for Finite Element Analysis of Load Distributions in Multi-bolt Composite Joints", P.J. Gray, C.T. McCarthy.

[12] "Numerical and Experimental Study of Shear Loaded Bolted Joint", Mohamed Tahar Nasraouia , Jamel Chakharib , Boubaker Khalfi , Mustapha Nasria, International Journal of Current Engineering and Technology ISSN 2277 - 4106 © 2013 INPRESSCO.