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Experimental And FE Analysis Of Eccentric Loaded Symmetrical And Unsymmetrical Bolted Joint With Bolt Pretension

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ABSTRACT
This paper presents experimental and FE analysis of eccentric loaded bolted joint under symmetric and unsymmetrical bolt system with consider bolt pretension. A cad model of a bolted joint has been developed using modeling software PROE5.0 and FE analysis was carried out by using ANSYSWORKBENCH12.0.stress analysis has been carried out by varying bolt pattern of bolted joint for predict maximum heavily loaded bolt. Experimental work was conducted to measure maximum shear strength of the specimens for validation of the developed FE model. Experimental work was carried out on hydraulic jack and specimen of bolted joint was tested to know maximum shear strength of bolt. The results from both FE analysis and experimental work were then compared and show close results among them.
Keywords: ANSYS WORKBENCH12.0, Bolt Pretension, FEM, PROE5.0.

I. Introduction

The Bolted joint is a very 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 spacecraft, ship, internal combustion engine, automobile, or oilrig, etc and for civil structure and pipelines. There are many applications of the bolted joints which are subjected to eccentric loading such as wall bracket, pillar crane etc. Eccentric loaded bolted joint under symmetric and unsymmetrical bolt system as shown in Fig1.1 and Fig1.2.

Bolted joints are critical structural regions and must be properly designed so that the desired performance from the overall structure is obtained. Because of large stress concentrations, joints can become a source of weakness if proper design practice is not followed. Accordingly, failures typically occurred at connections and interfaces, rather than within the bulk of the system. To provide a safe and cost-effective joint design, it is typical to configure the joint with respect to the geometry and the constituent materials, which affect both strength and failure modes.

When the secondary shear load on each bolt is equal, then the heavily loaded bolt will be one in which the included angle between the direct shear load and secondary shear load is minimum. The maximum heavily loaded bolt becomes the critical one for determining the strength of the bolted joint.

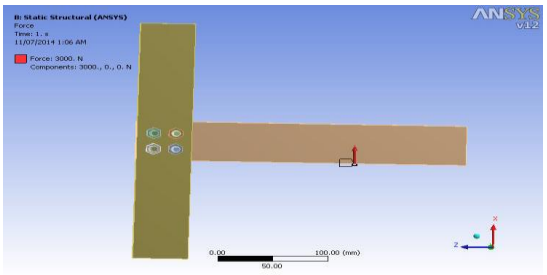

Fig. 1.1 Symmetrical eccentric loaded bolted joint

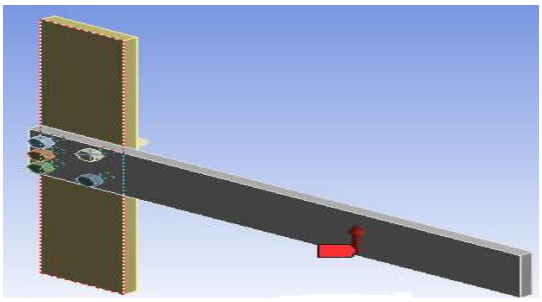
Fig. 1.2 Unsymmetrical eccentric loaded bolted joint

1.1 Objectives and Methodology

The main aim of this paper is to determine the stress distribution among region of failures for eccentrically loaded bolted joint and hence to carry out load carrying capacity of the bolt, also to study the effect of various design parameters as mentioned below.

1) To check performance of eccentric loaded bolted joint with symmetric pattern by consider bolt pretension.

2) To check performance of eccentric loaded bolted joint with unsymmetrical pattern by consider bolt pretension.
3) A physical model of eccentric loaded bolted joint with symmetric pattern prepared and stresses are analyzed experimentally.
4) A physical model of eccentric loaded bolted joint with unsymmetrical pattern prepared and stresses are analyzed experimentally
5) FEM results and experimental results are compared.

To meet with above mentioned objectives and for carrying out analysis, two models have been prepared as mentioned below.

Model 1: Single Lap eccentric loaded Bolted Joint of symmetrical bolt system also it is subjected to design value of preload i.e. 9940N.

Model 2: Single Lap eccentric loaded Bolted Joint of unsymmetrical bolt pattern with design value of preload i.e. 9940N

For numerical analysis FEM is widely used tool in design, the objective of which is to find the stresses and strain in weaker element of product. Hence FEM analysis is carried out by using standard commercial software which then compared with analytical results and hence validated with experimental result for one of the case that has been included for analysis

II. Determination of Breaking Stress in Symmetrical bolted joint by experimentation &its verification by FEM.

A bolted eccentric loaded joint as shown in fig. 2.1 is considered for determination of breaking strength. A prototype of eccentric loaded bolted joint for symmetrical bolt pattern is prepared & it is tested by using setup of hydraulic jack. The photographs of experimentation are shown in fig.2.1 to fig.2.4.

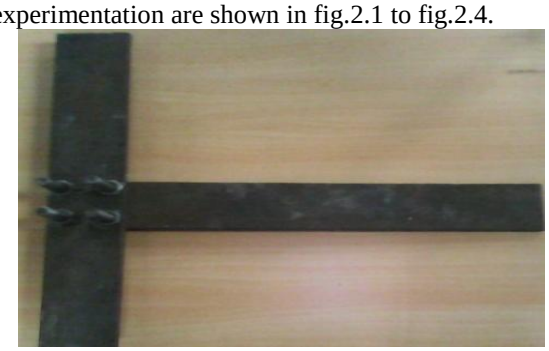

Fig 2.1 Test specimen

Fig 2.2 Mounting & Loading of Test specimen

Fig. 2.3 Dial shows Ultimate shear strength of bolt in KN

Fig 2.4 Failure of Test specimen

The bolt of diameter 7.0 mm has fail in breaking at a load of 3000 N which is the breaking strength for the bolted joint**.**

2.1 Analytical Calculation

load on Horizontal Plate(P) = 3000 N
Eccentricity (e) = 174mm
Plate dimension=300x50x8mm
Bolt diameter(*d)*=7.0mm

1) Center of gravity ‘G’ of bolt system: -

$$\bar{x} = \frac{x1+x2+x3+x4}{n}, \bar{y} = \frac{y1+y2+y3+y4}{n}$$

2) Direct shear load on each bolt :-

$$Ps = \frac{P}{n}$$

3) Turning moment produced by load P due to eccentricity(e) =Pxe

4) Equating the turning moment due to eccentricity of the load due to the resisting moment of the bolt,

$$PXe = \frac{F1}{L1}(L1^2 + L2^2 + L3^2 + L4^2 + \cdots)$$

From equation value of F1 calculated and

$$F2 = F1X\frac{L2}{L1}, F3 = F1X\frac{L3}{L1}$$

5) Resultant shear load,

$$R=\sqrt{Ps^2 + F^2 + 2Ps.F.\cos\theta}$$

6) Maximum shear stress ,

$$\tau_{max} = \frac{R}{\frac{\pi}{4}d2}$$

Breaking stress in shear by mathematical calculation has been found to be 253.96 MPa for symmetrical bolt pattern.

2.2 Determination of Breaking Stress by FE Analysis

Analysis of Bolted joint is carried out by considering data as per experimentation & analytical calculation.The analysis is carried out by developing a model of eccentric loaded-joint on modeling software PRO ENGINEER 5.0 and this model is imported in ANSYS WORKBENCH 12.0.

2.2.1 Material Data

Table 2.2.1 Properties and dimension of Bolt and nut

Material type	Medium carbon steel,Quenched and tempered
Modulus of elasticity, E	200 Gpa
Poisson's ratio, μ	0.29
Proof strength	580Mpa
Minimum tensile yield strength	640 Mpa
Minimum tensile ultimate strength	800 Mpa
Nominal length, L	45.74 mm
Nominal diameter, D	10 mm
Height of bolt, H	7.0mm
Width across flat, F	17.9 mm
Width across corners, C	20 mm
Height of nut	8 mm

Table 2.2.2 Properties and dimension of the Plates

Material type	Mild steel
Modulus of elasticity	200 Gpa
Poisson's ratio	0.29
Thickness	10 mm
Width	50 mm

2.2.2 Static Structural Analysis

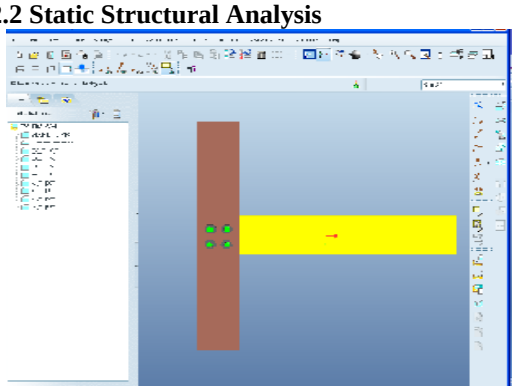

Fig 2.5 Geometrical model of Test specimen

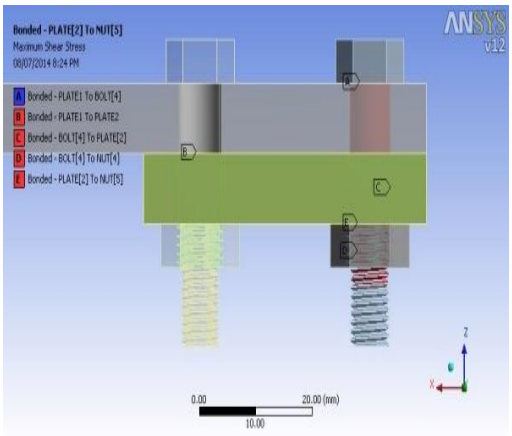

Fig 2.6 Contact Region (Bonded Type)

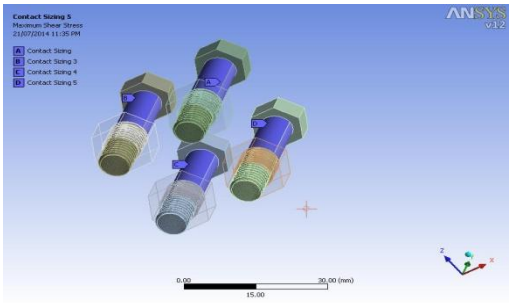

Fig 2.7 contact sizing

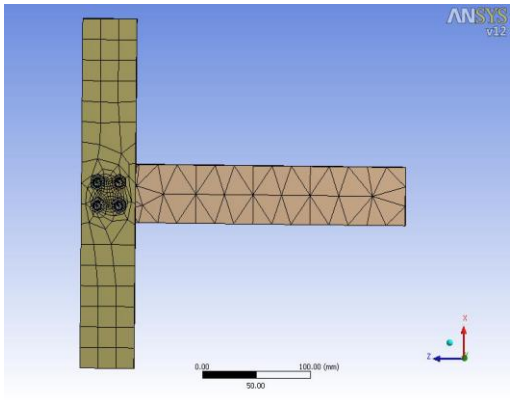

Fig 2.8 Meshing (Course Mesh)

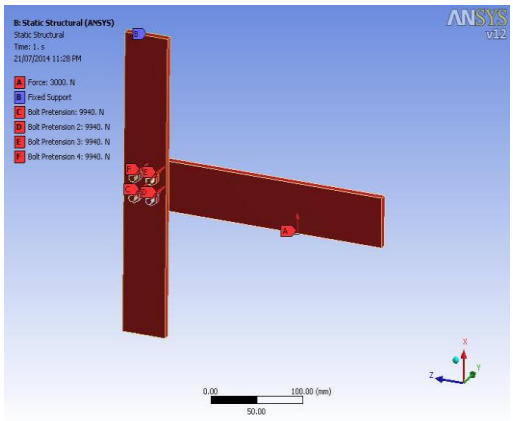

Fig 2.9 Boundary and Loading Condition

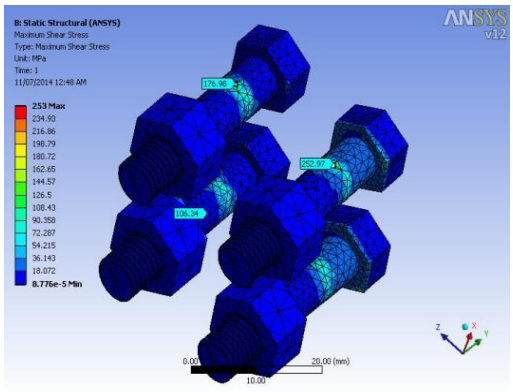

Fig 2.10 Solution

In analytical problem, the value of maximum permissible shear stress is 253.97 MPa and during FEM analysis, value obtained is in the range of 234MPa to 253MPa which is validated. Thus the FE model of bolted joint is validated for induced stresses.

III. Determination of Breaking Stress in Unsymmetrical bolted joint by experimentation & its verification by FEM

An unsymmetrical eccentric loaded bolted joint is considered for determination of breaking strength. A prototype of bolted joint is prepared & it is tested by using setup of hydraulic jack.The photographs of experimentation are shown in fig. 3.1 to fig.3.3

Fig 3.1 Test Specimen of Unsymmetrical bolted joint

Fig 3.2 Test Setup

Fig 3.3 Failure of Test specimen

The same experimental procedure has been applied for unsymmetrical bolt pattern which is previously discussed in section 4.2.After experimentation, bolt of dia 7.0 mm has fail in breaking at a load of 4000N which is the breaking strength for the bolted joint**.**

3.1 Analytical Calculation

The breaking stress determined from the breaking strength determined experimentally is calculated as follows:
Breaking Load(P)=4000 N
Eccentricity(e) = 174mm
Dimension of plate=300x50x8mm
Bolt dia(*d)*=7.0mm
No of bolt, n=5nos
Breaking stress in shear by mathematical calculation has been found to be 230.28 MPa for unsymmetrical bolt pattern.

3.2 Determination of Breaking Stress by FE Analysis for Unsymmetrical Bolted joint

Analysis of Bolted joint is carried out by considering data as per experimentation & analytical calculation. The same FE analysis commands have been utilized for unsymmetrical bolt pattern which are previously discussed in section 2.2.2 Material properties have been remaining same which are taken in symmetrical bolt pattern in section 2.2.1.

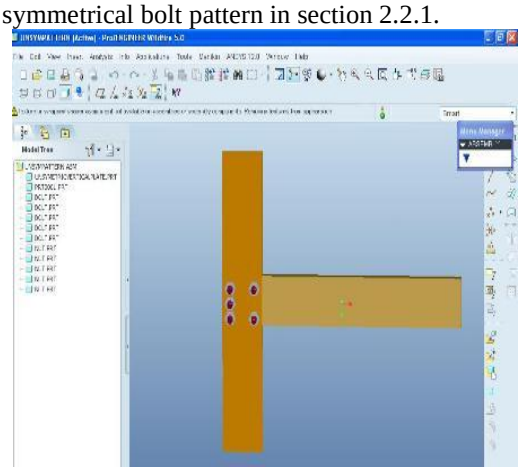

Fig 3.4 Geometrical model of Test specimen

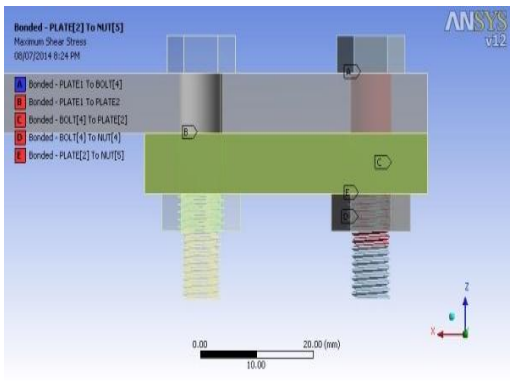

Fig 3.5 Bonded Contacts

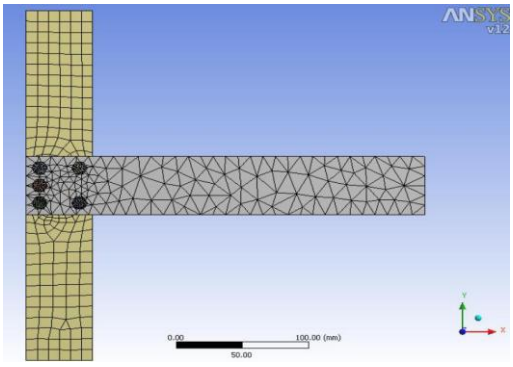

Fig 3.6 Meshing

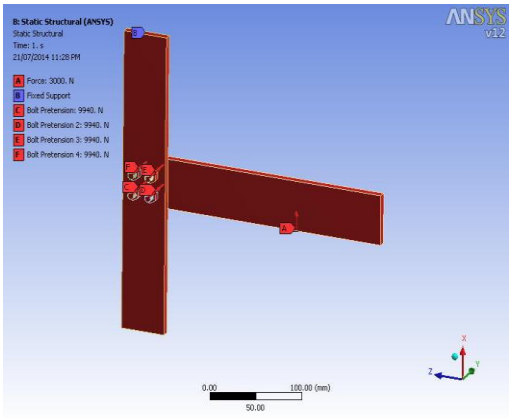

Fig 3.7 Boundary and loading condition

Load value is taken from experimentation result i.e.4000N.

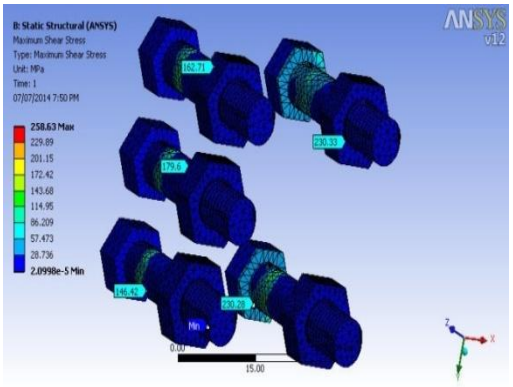

Fig 3.8 Solution

In analytical calculation, the value of maximum permissible shear stress is 230.28 MPa and during FEM analysis, value obtained is 230.33 MPa which is validated. Thus the FE model for unsymmetrical bolted joint is validated for induced stresses.

IV. Result

Results of Numerical calculation for all models considered for analysis are listed in tabular form as follows in Table no. 5.1

Table 5.1 numerically determined stresses for all models under analysis

Model No.	Maximum shear Stress	
	Bolt Shank	
	Ave	Max
Symmetrical bolted joint	236	253
Unsymmetrical bolted joint	146	230

Results of Analytical calculation for all models considered for analysis are listed in tabular form as follows in Table no.5.2

Table 5.2 analytically determined stresses for all models under analysis

Model prepared for analysis	t (mm)	d (mm)	Pi (N)	τ_{max} (MPa)
Symmetrical bolted joint	8	7	9940	253.56
Unsymmetrical bolted joint	8	7	9940	230.28

V. Discussion and Conclusion

The discussion and conclusion on the basis of result is presented in this section. The experimental determination of breaking strength of symmetrical eccentric loaded bolted joint revealed the breaking stress is 253 MPa. The FE analysis of symmetrical eccentric loaded bolted joint for the same geometry revealed the maximum shear stress is in the range of 236 MPa to 253 MPa as shown in fig.2.10. This investigation revealed that the stress in the bolt calculated by experimentation & FE analysis are in close agreement, which validated the FE model of the eccentric loaded bolted joint considered for the analysis.

The experimental determination of breaking strength of unsymmetrical eccentric loaded bolted joint revealed the breaking stress is 230.28 MPa. The FE analysis of unsymmetrical eccentric loaded bolted joint for the same geometry revealed the maximum shear stress is in the range of 146 MPa to 230 MPa as shown in fig.3.8. This investigation also revealed that the stress in the bolt calculated by experimentation & FE analysis are in close agreement, which validated the FE model of the eccentric loaded bolted joint considered for the analysis.

From experimental and FE analysis of eccentrically loaded bolted joint using symmetrical and unsymmetrical bolt pattern as shown in fig.2.10 and fig.3.8 , it is observed that bolts which are nearer to point of loading are heavily loaded, hence failure of that bolt takes place at the shank of the bolt.

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