Design and Analysis of Steel Tension Members with Bolted End Connections

[1]S.P. Lawhate, [2]D.D. Date , [3]H.D. Jagdale, [4] S.B. Pawar

[1]ME Student, Mechanical Engineering Dept., Sriram Institute of Engineering, Paniv, Solapur University, India.
[2]Associate Professor, TPCT College of Engineering, Osmanabad.
[3]Assistant Professor, Indira College of Engineering and Management, Pune
[4]Lecturer, Automobile Engineering, Parikrama Polytechnic, Kashti, Ahmednagar
Email: [1]lawhatesandip22@gmail.com

Abstract- The purpose of this work is to investigate the effect of connection eccentricity and connection length on failure capacities of steel tension member with bolted end connection. Tension members are frequently used for lateral bracing and as truss elements. Such members have normally eccentric connections which results in bending of tension member. It is often permitted by, current design specifications, to neglect this eccentricity in the design of member. The present study is focus on examining the effect of varying connection eccentricity and connection length on the ultimate capacity of bolted tension member. In present study connection length is increased by increasing the pitch between the holes instead of increasing the number of bolts. In this work six experimental tests are carried out on Tension members fastened with bolts, to calculate the failure capacity and also to trace the entire load versus deflection path. In this work finite element analysis of tension members carried out. Results of finite element analysis are compared with experimental results. The failure capacities predicted by FEA are in close agreement with the experimental observed failure capacities of the tension member subjected to tensile loading.

Keywords— Tension members; Bolts; Tensile Testing; FEA; Failure Modes; UTM

I. INTRODUCTION

1.1 Structure - Structure is a free-standing, immobile outdoor construction. Typical examples include buildings and non-building structure ones such as bridge sand dams. Some structures are temporary, built for some events such as trade shows, conferences or theatre, and often dismantled after use. Temporary structures have fewer constraints relating to future use and durability. Some structures are permanent.

1.2 Truss - Truss is a structure, comprising one or more triangular units constructed with straight members whose ends are connected at joints referred to as nodes. External forces and reactions to those forces are considered to act only at the nodes and result in forces in the members which are either tensile or compressive forces. A planar truss is one where all the members and nodes lie within a two dimensional plane, while a space truss has members and nodes extending in to three dimensions.

1.3 Tension Member - Tension members are structural elements or members that are subjected to axial tensile forces. Fig. 1.1 shows a member under tension. They are usually used in different types of structures. Examples of tension members are: bracing for buildings and bridges, truss members and cables in suspended roof systems.

In an axially loaded tension member, the stress is given by:

$$F = P / A$$

Where, P is the magnitude of load and A is the cross-sectional area.

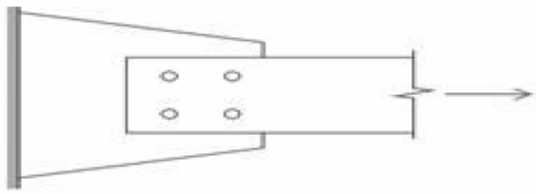

Fig. 1.1 Member under tension

1.4 Design of tension member - In order to design tension members, firstly, it is important to analyze how the member would fail under both yielding (excessive deformation) and fracture which considered the limit states. The limit state that produces the smallest design strength is considered the controlling limit state; which also prevent the steel structure from failure. Using AISC (American Institute of Steel Construction), we could obtain the recommended load and resistance factor design approaches. In the design of a tension member, secondly, it is important to select which type of member and the size of the member is required. The type of member is usually dictated by the location where the member is used. In the case of roof trusses, for example, angles or pipes are commonly used. Depending upon the span of the truss, the location of the member in the truss and the force in the member either single angle and double angle may be used in roof trusses.

1.5 Tensile testing - The mechanical properties of a material describe the behavior of material due to physical forces. Mechanical properties occur as a result of the physical properties inherent to each material, and are determined through a series of standardized mechanical tests. One of them is tensile test. A tensile test, also known as tension test, is probably the most fundamental type of mechanical test performed on material. Tensile tests are simple, relatively inexpensive, and fully standardized. By pulling on something, it can be quickly determined how the material will react to forces being applied intension. As the material is being pulled, strength can be calculated along with how much it will elongate. The results of tensile tests are used in selecting materials for engineering applications. Tensile properties frequently are included in material specifications to ensure quality. Tensile properties often are measured during development of new materials and processes, so that different materials and processes can be compared. Finally, tensile properties often are used to predict the behavior of a material under different forms of loading. Stress-strain curves generated from tensile test results help engineers gain insight into the constitutive relationship between stress and strain for a particular material. The stress-strain curve can also be used to qualitatively describe and classify the material [13].

1.6 Objective - The purpose of the present work is to investigate the effect of connection eccentricity and connection length on the failure capacities of tension members with bolted end connections. In this the connection length is increased by changing the pitch not by increasing the number of bolts. Besides the strength of the member, strain distributions at the critical section corresponding to stress and the deformations of the specimens corresponding to load were also examined. A total of six specimens were tested. Only one line of bolts was considered. All tests were performed at HSBPVT Parikrama Polytechnic, Kashti using 1000 KN Universal Testing Machine.

II. SPECIMEN GEOMETRIESS

The experimental testing consists of two sets of tension members (specimens) fabricated from rolled steel. There are total six specimens each of 600 mm length. The testing consists of two sets of specimens with same eccentricity but different connection length, i.e. 50 mm and 75 mm. Connection length was decreased or increased by varying the pitch. All specimens are fastened, with a single row of 15 mm A490 bolts, through their webs at both ends, shown in Fig. 2.1 [13] and Table. 2.1. The end distance and number of bolts for each specimen are held constant at 42and 3 respectively. Holes for the 15 mm A490 bolts were specified to be drilled to a 16 mm diameter.

Common Dimensions for all Tension Members (specimens) No. of bolts- 3

End distance- 42 mm

Specimen depth (d) – 90 mm

Flange thickness (t_f) – 5 mm

Web thickness (t_w) – 4 mm

Hole diameter (d_h) – 14 mm

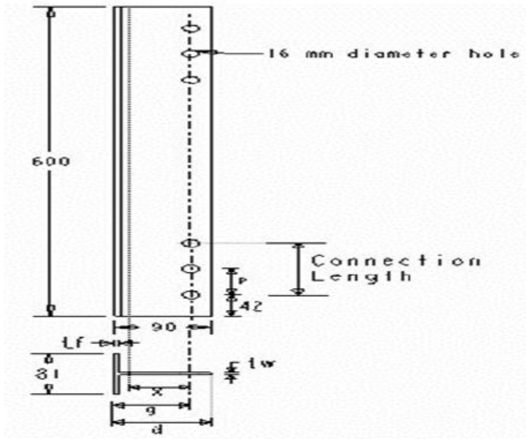

Fig. 2.1 Typical specimen's configuration

Table 2.1 Specimen dimensions and material strength

(All Dimensions in mm)

Spec . No.	Conn. Length L	Gage Distance G	Bolt line Eccentricity X	Tensile strength (Mpa)	Tensile Strength (Mpa)
1	100	70	48.6	250	460
2	100	58	36.6	250	460
3	100	46	24.6	250	460
4	150	70	48.6	250	460
5	150	58	36.6	250	460
6	150	46	24.6	250	460

III. EXPERIMENTAL SET UP

The experimental tests were carried out using Universal Testing Machine. After the appropriate grips were fastened to the specimen-grip assembly was then placed and centered in the UTM and then secured fast grips in the UTM grippers shown in Fig. 3.1. Each specimen was tested to failure by steadily increasing the applied load. With all instrumentation zeroed, the tensile load was then applied in control with strain rate of 1.8 mm per minute. Stress-Strain and static load- deformation readings were obtained. Sigma plot was used to monitor the stress versus strain and load versus elongation behavior of the test. Bar stock grips, are used to transfer the load from a 1000 KN universal testing machine (UTM) to a specimen. They are fabricated from mild steel bar stock and had 14 mm diameter holes drilled at the appropriate pitch. Two sets of bar stock grips were used in this study.

IV. SPECIMEN MODE OF FAILURES

The typical specimen failures (specimens: 1, 2, 3, 4, 5, 6) consists of a partial rupturing g of the net section. Tests were stopped when the peak load was reached. The peak load was reached before fracturing of the full net section, but after rupture of the partial net section. Fracturing of a specimen's web initiated at the lead bolt hole and propagated to the web's outside edge. Necking down of the tension plane area preceded fracture.

Specimens with small eccentricities exhibited a significant amount of bolt whole deformation. However, it was observed that the amount of deformation decreased with increasing eccentricity. Those specimen with the largest eccentricities demonstrated very minor whole deformation except at the lead and last bolts [13]

Fig. 3.1 Specimen grip assembly in UTM

Table 3.1 Experiment results for specimen 1

Force (KN)	Displacement	Stress	Strain
5	1.22	5	0.0014
25	5.25	25	0.0058
75	9.70	110	0.0180
110	12.60	150	0.0220

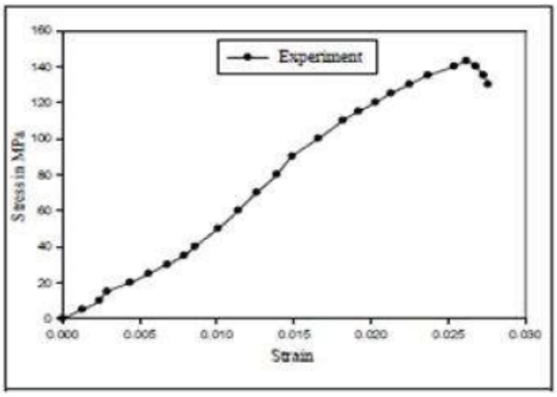

Fig. 3.2 Experimental graph for specimen 1

(Stress Vs Strain)

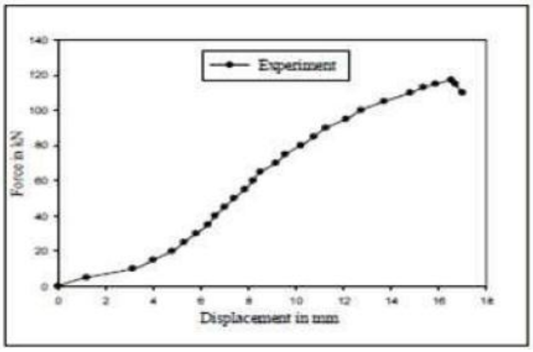

Fig. 3.3 Experimental graph for specimen 1 (Force Vs Displacement

Fig. 4.1 Partial net section ruptures, with small eccentricity

Fig. 4.2 Partial net section ruptures, with large eccentricity

V. FINITE EL EMENT ANALYSIS

The finite element model was prepared in ANSYS Workbench. The main objective of the FEA is not only to estimate the failure loads of the specimens but also to trace the entire load versus deflection path. The specimen grip assembly used in ANSYS is shown in Fig. 2.1. The typical mesh used in the Finite Element Analysis is shown in Fig. 5.1 and Fig. 5.2 shows the s tress (MPa) and strain contour for specimen 1.

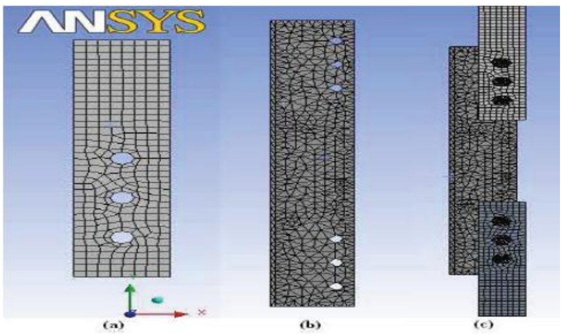

Fig. 5.1: Typical Finite Element mesh (a) Gusset plate (b) Specimen (c) Full assembly

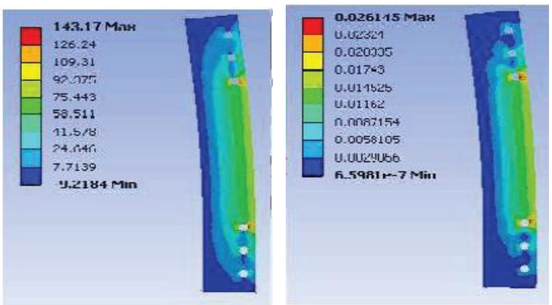

Fig. 5.2 Stress contour and strain contour of specimen specimen 1

Table 5.1 Simulation results for specimen 1

Force (KN)	Displacement	Stress	Strain
5	1.15	5.05	0.0015
25	4.75	26.25	0.0069
75	10.15	101.35	0.0186
110	14.75	139.26	0.0240

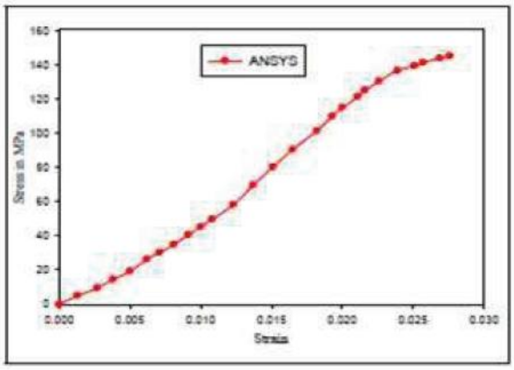

Fig. 5.3 Analytical graph for specimen 1

(Stress Vs Strain)

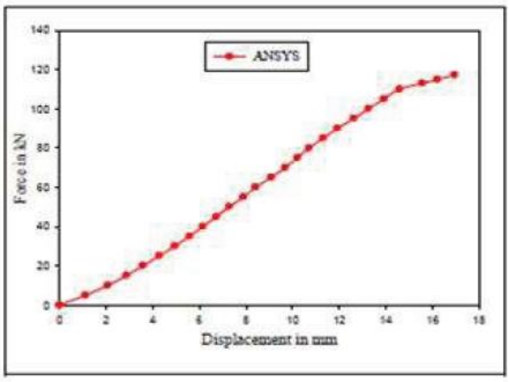

Fig. 5.4 Analytical graph for specimen 1

(Force Vs Displacement)

VI. RESULTS COMPARISON EXPERIMENTAL VS ANSYS FOR SPECIMEN 1

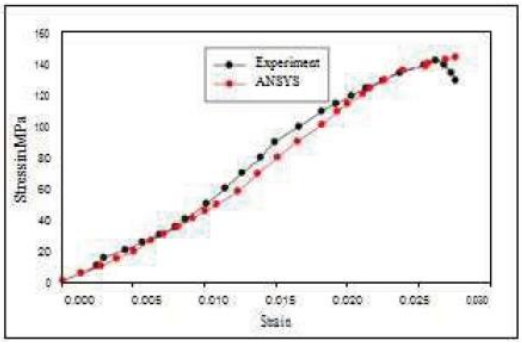

Fig. 6.1 Comparison of Experimental Vs ANSYS for specimen 1
(Stress Vs Strain)

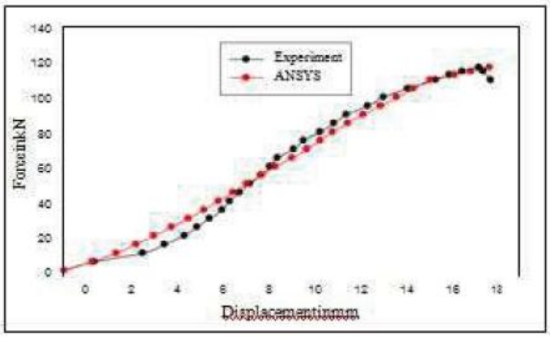

Fig. 6.2 Comparison of Experimental Vs ANSYS for specimen 1
(Force Vs Displacement)

VII. CONCLUSION

The study focused on examining the effect of varying connection eccentricity and connection length on the ultimate capacity of the bolted tension members. Here the connection length is increased by increasing the pitch between the holes instead of increasing the number of bolts. In all of the specimens, failure is caused due to the partial net section rupture of the connected leg adjacent to the lead bolt hole. The Finite Element Analysis presented here is capable of not only predicting the failure capacities but also in tracing the entire load versus deflection path. The analysis indicated an excellent agreement with the experimental failure capacities of the specimens with large connection eccentricities. In addition, these models are able to accurately capture the partial net section rupture failure mode observed in the experimental specimens.

VIII. ACKNOWLEDGMENT

I would like to thank Prof. A. N. Patil and Mr. N. G. Kale for the valuable suggestions & support to publish this paper. And also thankful to all the authors who worked on Failure Capacities of Steel Tension Member without whose help the work would not have seen the light of the day.

REFERENCES

[1] M. Gupta and L. M. Gupta, “Evaluation of stress Distribution in bolted steel angles under tension”,

Electronic Journal of Structural Engineering, vol. 4, pp. 17-27 (2004).

[2] C. H. Michael, Y. C. Yama, Zhongb, C. C. Angus, Lamb And V. P. Iub, “An investigation of the block Shear Strength of coped beams with a welded clip angle Connection—Part I: Experimental study”, Journ al of Constructional Steel Research, vol. 63, pp. 96–115 (2007).

[3] C. H. Michael, Y. C. Yama, Zhongb, C.C. Angus, Lamb And V. P. Iub, “An investigation of the block Shear strength of coped beams with a welded clip angle Connection—Part II: Numerical study”, Journal of Constructional Steel Research, vol. 63, pp. 116-134 (2007).

[4] V. F. de Paulaa, L. M. Bezerrab, and W. T. Matiasb, “Efficiency reduction due to shear lag on bolted cold-Formed steel angles”, Journal of Construction al Steel Research, vol. 64, pp. 571–583 (2008).

[5] A. Bouchair, J. Averseng and A. Abidelah, “Analysis of the behavior of stainless steel bolted connections”, Journal of Constructional Steel Research, vol. 64, pp. 1264–1274 (2008).

[6] T. Ranawaka and M. Mahendran, “Experimental study ofthe mechanical properties of light gauge cold-formed Steels at elevated temperatures”, Fire Safety Journal, vol. 44, pp. 219-229 (2008).

[7] T.N. Chakherlou, R.H. Oskouei and J. Vogwell, “Experimental and numerical investigation of the effect Of Clamping force on the fatigue behavior of bolted plates”, Engineering Failure Analysis, vol. 15, pp. 563–574 (2008).

[8] Ed.Chaen Wai-Yu, W.W.”Cold formed steel Structures” Structural engineering Hand Book”. By, Xiao-Ling Zhao Tim Wilkinson and Gregory Hancock Cold Formed Tubular Members And Connections January 2005.

[9] Bouchair et al. In 2008 studied “Analysis of the behavior of stainless steel bolted connections”.

[10] “Failure Modes of Bolted Sheet Steel” By Colin A Rogers, Gregory J Hancock.

[11] K. E. Barth, J. G. Orbison and R. Nukala, “Behavior Of Steel tension members subjected to uniaxial Loading”, Journal of Constructional Steel Research, vol. 58, pp. 1103–1120 (2002).

[12] “Failure mode of steel in tension member due t Change In connection eccentricity and connection Length”. By Diwakar Kumar.

◈◈◈