J. Basic. Appl. Sci. Res., 1(9)989-997, 2011

ISSN 2090-424X
Journal of Basic and Applied Scientific Research
www.textroad.com

Static Strength Analysis of Tubular T-Joints Using Ansys

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ABSTRACT

A Finite element analysis has been done using ANSYS, to study the static strength of an offshore tubular T-joint. The strength of T-tubular joints with circular cross section tube chord with circular cross section tube brace is investigated. To determine the joint strength of these T-joint subjected to tension, compression, in -plane bending and out-of-plane bending loading cases have been carried out. The main objective of this work is to study the effect of static strength of T-tubular joint under various loading cases by using ANSYS. In this investigation, the displacements, stresses and yield points are obtained from finite element method. Results are compared with circular chord tubes under different loading cases. Finite element ANSYS results have been validated with the experiment results. Reasonable agreement was obtained between the finite element analysis results and the experimental values for all loading cases. The difference varies between 4.104 and 7.14 percent. This is well within the experimentation error limit of 10 percent. A comparison between the results of LUSAS Finite Element Analysis and present Finite Element Analysis through ANSYS is quite exhilarating. Another comparison with existing tubular joints design formulae showed that these formulae were conservative and highly safe for the geometrical use.

KEY WORDS: Tubular joints, T- joints, Circular chords, Brace, finite element analysis.

NOMENCLATURE:

d = brace diameter l= length of brace
D = chord diameter T=thickness of chord
L= length of chord t= thickness of brace

$$\beta = \frac{d}{D}$$

1. INTRODUCTION

1.1 Offshore Structures

Steel tubular framed structures called offshore platforms are installed on seabed for exploration and production of oil from the sea bottom. These serve as bases, supporting the drilling and production facilities above the elevation of waves. At present, there are over 7000 offshore platforms worldwide. There are about 148 platforms in the Bombay High and other fields in the Arabian Sea and 10 platforms in the Ravva field of Bay of Bengal. The typical structure consists of

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a deck, a substructure and foundation piles as shown in Figure 1.1. The substructure is a pre-fabricated tubular space frame, which extends from the sea floor to just above the sea surface, and is usually fabricated in one piece on shore transported by barge launched at sea, and up ended on site by partial flooding. Tubular pilings are driven through the main legs to fix the structure to the sea bottom, provide support for the deck and resist the lateral loadings due to wind and waves.

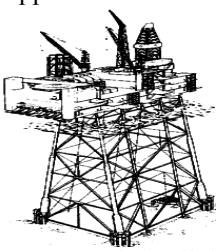


Figure 1.1 A Typical Off-shore structure

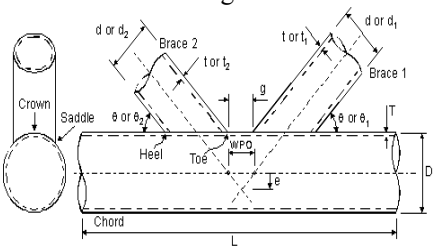


Figure .1.2 Tubular joint notations

1.2 Tubular joint Notations and Geometric classifications

Simple welded joints are those that are formed by welding two or more tubular members in a single plane without overlapping of brace members and without the use of gussets, diaphragms, stiffeners or grout. Unlike a pipe joint, the chord wall is left intact with the hidden plug regions enclosed by the braces. The geometric and other notation for a simple joint is shown in Figure 1.2. As for the member geometries, a tubular joint may have different numbers of brace members meeting the chord at various angles and positions. These varying configurations are commonly referred to by an alphabetic letter corresponding to the shape of the joint. The nomenclature for simple joint configurations is shown in Figure 1.3.

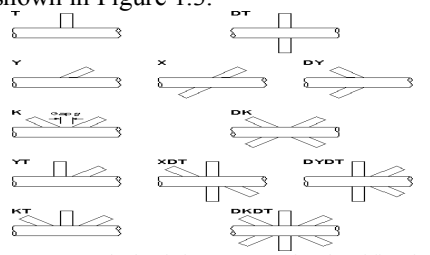


Figure-1.3 Tubular joint geometric classifications

1.3 LITERATURE REVIEW

Tubular joints are widely used as the main components of construction elements for offshore structures. The tubular frame structures are installed on the sea bed for exploration of oil from sea bottom. In the tubular frame the intersection between two members is called a tubular connection. A weld joint at the interface created between the members in tubular connections consists of the weld deposit and adjacent base material. The main member is referred to as chord and the secondary member as the brace. Common Connection types of tubular structures may consists of more than one bracing member or branch that is weld directly to the main chord is strengthened by increasing wall thickness.

Generally the outside diameter of the brace is less than or equal to chord. The joint without any reinforcement is called an unstiffened joint. Tubes of different cross sections are commonly used. Rectangular hallow sections used by Ono [1] square hallow cross sections used by Rasmussen

[2]**.** Circular cross section tubes are preferable to other types of sections and are used extensively in offshore structures as their drag characteristics minimize wave forces on the structure, and their closed cross section allows for the needed buoyancy during installation in the ocean environmental. These circular tubes are also more convenient to use than other tube shapes because of their availability in different sizes. Kanatani [3] carried out some experimental studies in 1986 on welded tubular connections with different load cases. However, this was limited to only circular tubular joints. Hamed [4] recently conducted few experimental tests on elliptical T-tubular joints and compared with circular chord tubular joints. The subject of this investigation was first approached through finite element analysis of the tubular joints by Jubran and Cofer [5] who employed solid elements to generate T joint model. This is found to be successful for evaluating the ultimate joint load. Kalid et.al [6] employed shell elements to tackle the stress analysis problem of T tubular joints. The results were compared with experimental data. Thandava Murthy [7] conducted experimental analysis of unstiffened T-joints and evaluated their strength under axial compression. Chen and WU [8] used shell elements to model the elastic plastic behaviour of T joints with small deflection. A non-linear finite element computer program was developed by Cofer & Will [9] to model welded tubular joints. Excellent results were obtained for T-joints and DT joints. Lalani and Bolt [10] discussed the strength of Multi-planer joints on offshore platform. Here the experimental results were compared with Finite Element Data. Ebecken. *et. al*. [11] employed elastic–plastic analysis for tubular joints using finite element Method. Beale and Toprac [12] analyzed in-plane T, Y, and K welded tubular connection through theoretical formulae. Bolt.et.al [13] described the influence of chord length and boundary conditions on K joint strength. Pan and Plummer [14] described the ultimate strength of tubular joints using the design codes. Soh [15] developed equations per computing the strength of DT/X square to round tubular joints. Vender and Lu [16] gave non-linear behavior of uni-planar tubular steel joints under out of plane bending.

2. MODELING OF TUBULAR T-JOINT

2.1 Geometric model of the T-joint

The geometry and the dimensions of the T-joint under study are same as those subjected to experimental investigation by Hameed et al [6] as given in Table 2.1 The material used in all cases is mild steel.

Table 2.1 Geometric Parameters of the Modeled T-joint

Geometric parameter	Chord	Brace
Diameter	76.2	42.5
Length	440.0	200.0
Thickness	2.0	2.0
All dimensions are in mm		

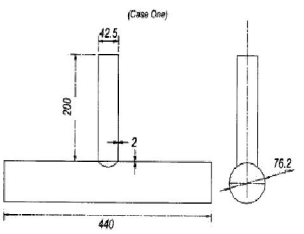


Fig 1.4 Geometry of the model tested (all dimensions are in mm)

2.2 Boundary conditions

In experimental study, the chord ends are usually bolted. As one of the objectives of the current study is to replace experimental study, the boundary conditions applied to the chord member of the T-joints are approximated to chord end fixity for all degrees of freedom.

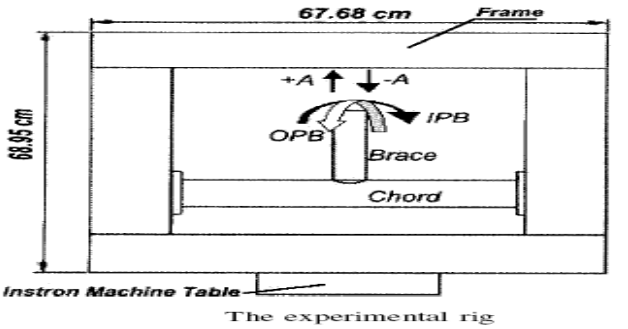


Fig 2.1 experimental test rig (reference from [6])

For tension and compression loading, the loads are uniformly distributed at every node of the free end of the brace where the upward is for tension loading and the downward is for compression loading. For IPB loading and OPB loading, the loads are applied to two points at the free end of the brace where the distance between the two points is the brace diameter (*d*). The load applied at the two points will create a couple (moment) at the free end of the brace and cause the brace to deflect on one side depending on the way the load is applied. For IPB, the direction of deflection will be parallel to the chord tube while for OPB the direction of deflection will be perpendicular to the chord tube. Only elastic analysis was carried out.

2.3 Loading conditions

The chord is held as fixed –fixed from both ends. Detailed weld fillets are not modeled. The loads are applied for all the types to the free end of the brace in different directions, depending on the load type. For tension and compression loading, the loads are uniformly distributed at every node of the free end of the brace, where the upward is for tension loading and downward for compression loading. For IPB loading and OPB loading, the loads are applied to two points at the free end of the brace, where the distance between the two points is the brace diameter'd'. The load applied at the two points will create a couple (moment) at the free end of the brace and cause the brace to deflect on one side, depending on the way the load is applied. For IPB, the direction of deflection will be parallel to the chord tube while for OPB the direction of deflection will be perpendicular to the chord tube.

2.3.1 Finite Element Results for Tension Loading for Circular T–Tubular Joints

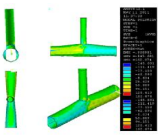


Fig 2.2 Ansys output

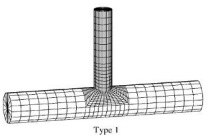


Fig 2.3 Lusas output (reference from [6])

2.4 Equations in static analysis

After using a discretization scheme to model the continuum, we have obtained an expression for the total potential energy in the body as

$$\Pi = \tfrac{1}{2} Q^T KQ - Q^T F \qquad (2.1)$$

Where K is the structural stiffness matrix, F is the global load vector, and Q is the global displacement vector

Von Mises Stress

Von Mises stress is used as a criterion in determining the onset of failure in ductile materials. The failure criterion states that the Von Mises stress σ_{VM} should be less than the yield stress, σ_Y of the material. In the inequality form, the criterion may be put as

$$\sigma_{VM} \leq \sigma_Y \qquad (2.1)$$

The Von Mises stress σ_{VM} is given by

$$\sigma_{VM} = \sqrt{I_1^2 - 3I_2} \qquad (2.3)$$

Where I_1 and I_2 are the first two invariants of the stress tensor. For the general state of stress I_1 and I_2 are given by

$$I_1 = \sigma_x + \sigma_y + \sigma_z$$

$$I_2 = \sigma_x\sigma_y + \sigma_y\sigma_x + \sigma_Z\sigma_x - \tau^2_{yz} - \tau^2_{xz} - \tau^2_{xy} \qquad (2.4)$$

In terms of the principal stress σ_1, σ_2, and σ_3, the two invariants can be written as

$$I_1 = \sigma_1 + \sigma_2 + \sigma_3$$

$$I_2 = \sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_3\sigma_1 \qquad (2.5)$$

Von Mises stress can be expressed in the form

$$\sigma_{VM} = \frac{1}{\sqrt{2}} \sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_{31})^2} \qquad (2.6)$$

3. RESULTS AND DISCUSSION

The finite element model of the T-joint, created using ANSYS pre-processor is shown in Figure 3.1. Figure 3.2 to 3.6 represents the displacement distribution of the chord through out its length for various loading conditions.

3.1 Compressive Load Simulation

The meshed model of the T-joint, when subjected to axial compressive load, revealed that the portion of the chord directly under the brace is subjected to high stresses. Von Mises equivalent stress is taken to define yield point. The joint yielded at a compressive load of 25KN. The detailed

vertical displacement distribution on the chord at yield is shown in Figure 3.3. For the length of the chord of nearly three times the chord diameter near the intersection of the members, the displacements are found to be high. As expected the displacements are greatest at the intersection of the branch and chord.

3.2 Tensile Load Simulation

Under a tensile load, large deformation and yielding are observed in the portion of the chord directly under the brace. Yield is observed at a load of 27KN, the vertical displacement distribution on the chord is shown in Figure 3.4. The displacements are found to be high in a length of nearly three times the chord diameter near the intersection of the members similar to the case of compressive load.

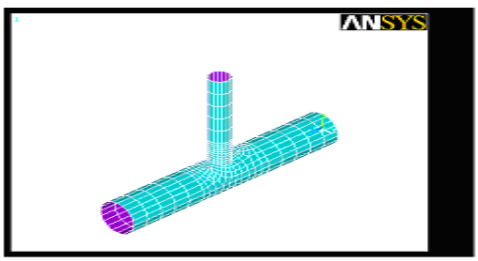
3.3 In-Plane Bending Moment Load Simulation

Under in-plane bending moment load, the portion of the chord adjacent to the intersection of the members yielded. The Von Mises stresses are found to equal the yield stress at a bending moment load of 0.6 KN-m. The vertical displacement distribution is shown in Figure 3.5. It is observed that one side of the brace acts as tension side and other side as compressive side, with the portion of the cord directly under the brace acts as translational stage between the two sides.

3.4 Out-of -Plane Bending Moment Load Simulation

Under out-of-plane bending moment load, the portion of the chord directly under the brace is found to yield at a load of 0.39 KN-m, the vertical displacement distribution on either chord horizontal diametral ends over its length are shown in Figure 3.6 and Figure 3.7.

Vertical displacement distribution on the chord unde various moments



3.1: Finite element model of the tubular joint

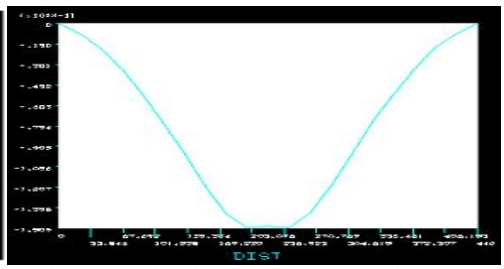


Figure 3.2: the chord under compression

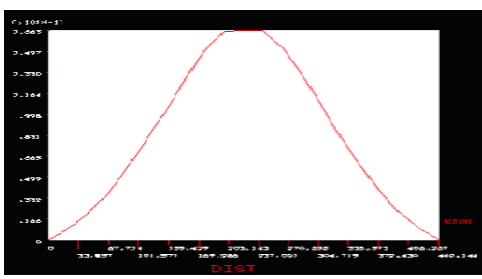


Figure3.3: under tension

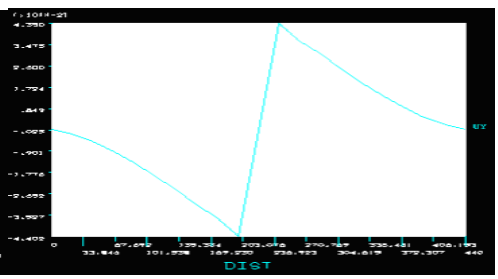


Figure 3.4 In-plane bending moment

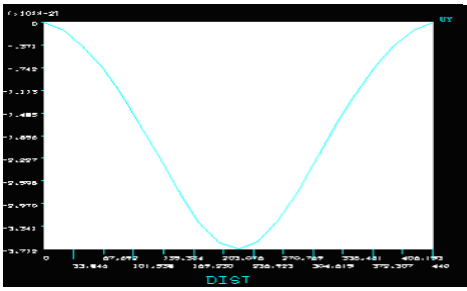


Figure 3.5: compression end of the chord under plane bending moment

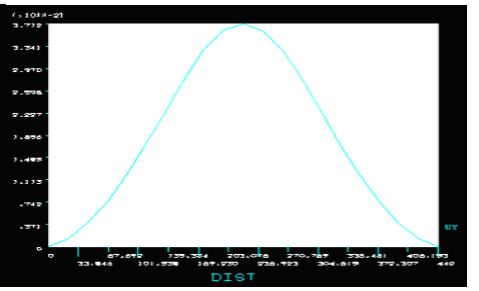


Figure 3.6: on the tension end of the chord under out of plane bending moment

3.5 Error Estimation of the Results

The accuracy of the finite element solution depends on the discretization, which is characterized by the finite element mesh and the choice of elements. To determine this accuracy, ANSYS package offers an advanced feature of Adaptive Meshing technique. With this feature, errors in the solution are identified and if necessary, mesh refinement is done automatically by the software itself. In the present study, finite element results are found to be within the default error estimates of ANSYS software and hence, the results obtained are accurate.

3.6 Comparison of Finite Element Results with Experimental Values

One of the objectives of this work is to compare the finite element results with the experimental test results of Hameed et al [4]. The comparison is shown in Table 3.1.
From the two results it can be observed that the % error is within the accepted error limit of 10%. Hence it can be concluded that Ansys provides a good agreement with the experimental results for Tubular T-joint.

Table 3.1 Comparison between the Experimental and Finite element results

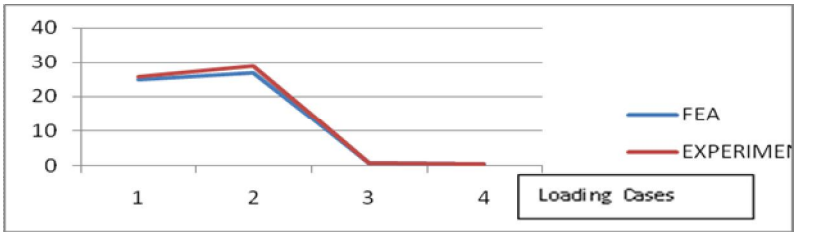
Loading case	Yielding point (FEA)	Yielding point (Experiment)	% Error
Tension (KN)	27.00	29.07	7.12
Compression (KN)	25.00	26.0	4.10
In-Plane bending (KN-m)	0.60	0.64	6.25
Out-of-Plane bending (KN-m)	0.39	0.42	7.14

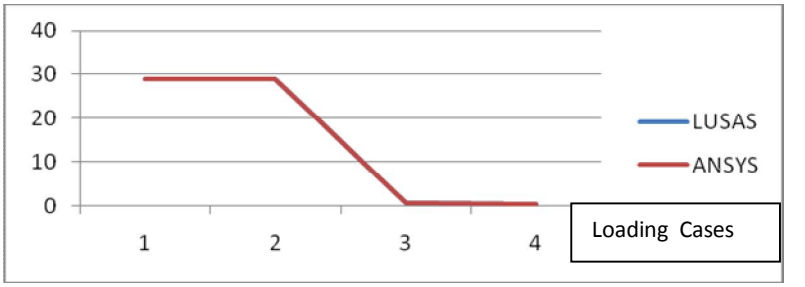
3.7 Comparison of ANSYS and LUSAS finite element analysis [refernce no.6] results at average yield points Type -1 Circular –Circular

Table 3.1 Comparison between the ANSYS and LUSAS Finite element analysis results

Loading case	Yeilding Point (LUSAS)	Yeilding Point (ANSYS)
Tension (KN)	29.00	29.00
Compression (KN)	29.00	29.00
In-Plane Bending (KN-m)	0.65	0.66
Out-Plane Bending (KN – m)	0.46	0.45

3.8 Comparison of ANSYS and LUSAS Finite Element Results for Circular Tubular T-joints.





4.**Conclusions**

The main conclusions which can be drawn from this investigation are summarized as follows:

1. The ultimate loads for tension is double that for compression for all types tested.
2. The ultimate moments for in plane bending is doubled that for Out plane bending for all cases.
3. Reasonable agreement was obtained between the plastic finite element analysis results and the experimental values for all loading cases. The difference varies between 4.104 and 7.14 percent. This is well within the experimentation error limit of 10 percent.
4. Using the displacement distributions, which were obtained from ANSYS, new Plastic design equations have been derived under different loading conditions for Tubular T-joint.
5. Having validated the ANSYS package for deriving Plastic design equations for the Tubular T joint, it can be expanded to model and design the inclined brace joints like Y, K and X.**5.**

Acknowledgements

Authors are very grateful to our beloved teacher Professor P.V.Krishnan, IIT-Delhi for his excellence in teaching and training that he has imparted and inspired.

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