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Understanding Behavior of X-Uni-planer Tubular Connections Using Finite Element Method of Analysis

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Abstract—*Support system in the form of vertical steel trusses, horizontal steel trusses, bow-string with strut profiles, glass supports, high tension cable supports are popular in India for commercial buildings like theatres, shopping malls, public buildings like airports, offices etc. However analysis of support systems of such structures subjected to different forces is critical due to intricate areas in connections and hence it becomes essential to understand behavior of such connections. From past literature it is observed that tubular connections with circular, rectangular sections are acknowledged due to their benefits in terms of economy, strength, aesthetic appearance, less and easy maintenance, quick joinery, durability etc. Tubular connections are classified as X, K, T, Y depending upon the load transfer and geometry. For the numerical formulation, a commercial building in Pune subjected to Wind + Dead load is considered having support system in the form of vertical steel trusses in a building envelope, developing a X-uni-planer tubular connections with boundary condition of one end fixed and other end radial restrained. Forces from truss system are evaluated by using SAP2000. Tubular members are designed using IS: 806:1968. Member forces in truss assembly are ultimately transferred on circular tubular connections to understand their response to the combination of forces. Finite element models for X-type overlapped tubular connections are developed in Ansys 14.5 and their behavior is observed with variation in parameters like angle between brace and chord, horizontal distance between chord axes to brace axis, vertical distance above axis of chord in the connections. Average stress is calculated from interaction curve and remark is given by suggesting stress intensity equation for mentioned boundary and loading conditions with variation in angle.*

Keywords: *Tubular connections, Support system, X-connection, Ansys models, Finite element method.*

1. INTRODUCTION

Use of steel tubular connections is beneficial in coastal areas, in commercial complexes due to their structural advantages in terms of strength, high moment of area which reduces buckling of column, aesthetic appearance and less corrosion. Basic components of tubular connections are chord and braces. Tubular connections are divided as-

- Depending upon number of planes involved in the connection
- Based on geometry of chord and braces
- Nature of forces acting on braces
- Based on connection between chord and braces

Trusses are popular support systems in commercial buildings like airports, shopping complexes, multiplexes, auditoriums, stadiums etc. These trusses can be oriented in vertical or horizontal format as per the requirement. Vertical trusses also act as a support system for structural glazing panels in commercial buildings.

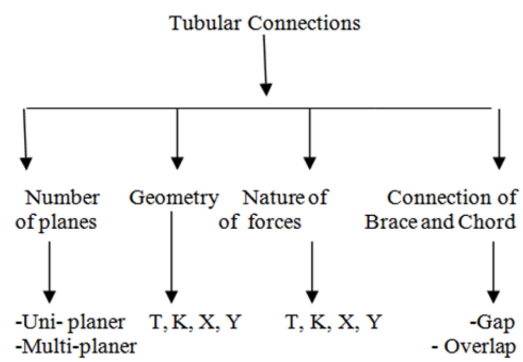

Fig. 1: Types of Tubular Connections
(Source: Author)

2. LITERATURE REVIEW

In the offshore structures stress concentration usually occurs at the intersection of tubular members (i.e. tubular joints). The member of greatest diameter is referred as the chord. The smaller diameter members are called as branches or braces. Because of the complexity in the geometrical configuration of tubular intersections as well as thin shell theory governing their behavior, reliable prediction of the stresses in such joints by analytical method proved to be costly as well as difficult. To solve these difficulties Finite element analysis seemed to offer natural solution. [2] Entire tubular connection can be sub-divided into different regions and in which each part was meshed with different element. It has been proved to be efficient in producing different quality mesh at different zones. [3] For uni-planer X-joints the welds were found to have relatively little effect on the joint strength. Fo joints without significant gaps, the use of weld- effect models generally makes little difference to the overall behavior and strength of the joint, therefore it is not a necessary feature for such joints. [4]

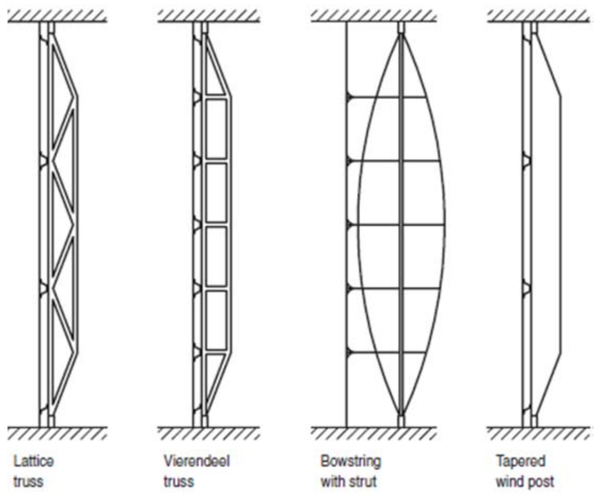

Fig. 2: Types of vertical trusses as a support systems [1]

3. PROBLEM FORMULATION

A 24m height truss with parabolic tubular profile is taken for analysis for a commercial building in Pune. Joints are uni-planer forming X connection as per nature of the forces acting on truss. Members of truss are made up of mild steel confirming to IS: 800:2007 standards. Minimum angle between chord and braces is 30° as per IS: 806:1968. To study the effect of angle on the strength of connection, variation in the angle is taken as 45˚ and 60˚ in addition to 30˚. Also, to understand the effect of variation in the position of brace location vertical eccentricity (s) is varied from 0, 5, 10 and 15mm with change in the horizontal distance of the connection (q).

4. NUMERICAL FORMULATION

Analysis is carried out in three stages-

- Stage 1-Analysis of Truss- Analysis of truss is carried out with the help of Finite element software SAP2000. Parabolic truss profile is taken for analysis with a height of 24metre. Load on truss is taken as combination of Dead load + live load as per IS:800: Part 3:1993

Geometry of Truss is as follows-

i) Cross section of members- Tubular ii) Pitch of truss: 30˚
iii) Centre to centre distance between trusses: 3metres iv) Rise of truss: 0.866metre
For Wind load calculations following considerations are made as follows-
i) Terrain Category : 3 ii) Wind Speed (V_b) : 39m/s iii) Structure class : B iv) Risk Coefficient (K_1) : 1 v) Topography Coefficient (K_2) : 1.02 vi) Coefficient (K_3): 1 vii) Permeability: Medium

- Stage 2- Design of Tubular members- Design of truss assembly carried out in four categories depending upon the nature of the forces as compression members, tension members, inclined braces and beams using IS:800:2007

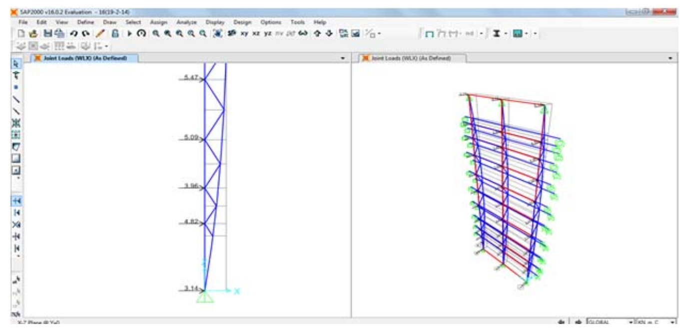

Fig. 3: Wind load applied on 24m Parabolic Truss in SAP-2000

- Stage 3- Analysis of Tubular Connections- Analysis of tubular connections is carried out using Finite element method. Finite element method is a powerful tool to solve complex material properties and boundary conditions. The entire procedure involves following procedure.

i) Dividing into equivalent system of finite element
ii) Selecting suitable displacement function
iii) Deriving element stiffness matrix using variation principle of mechanics (like principle of minimum potential energy)
iv) Formulating global stiffness matrix for entire body
v) Obtaining algebraic equations to determine unknown displacements
vi) Calculating element strains and stresses from nodal displacements.

Type of element used in Finite element method: [5]

- SOLID185- It is used for 3D solid modelling of the structure. It is defined by eight nodes having three degrees of freedom at each node i.e. translations in the nodal X, Y and Z directions. The element has plasticity, hyper elasticity stress stiffening, creep, large deflections and large strain capabilities. SOLID185 are degenerated into brick, prism, tetrahedral to use in irregular regions. (Refer Fig. 3) [15]

- SOLID-186 It is a higher order 3D-20 node solid element that exhibits quadratic displacement behavior. The element is defined by 20-nodes having 3 degrees of freedom at per node i.e. translations in X, Y and Z directions. The element has plasticity, hyper elasticity stress stiffening, creep, large defections and large strain capabilities. It is basically suited for irregular meshes. (Refer Fig.3)[15]

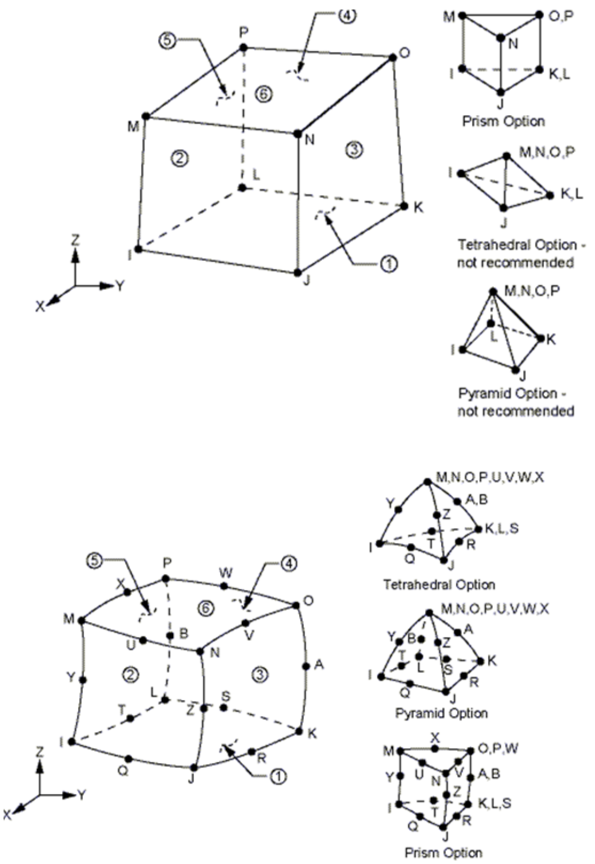

Fig. 4: SOLID 185 and SOLID 186-Structural Solid element in ANSYS14.5 [5]

Boundary Condition- One end of chord fixed and other end radial restrained.

Load on connection- Load calculated from analysis of tubular truss is applied on chord in the form of surface load.

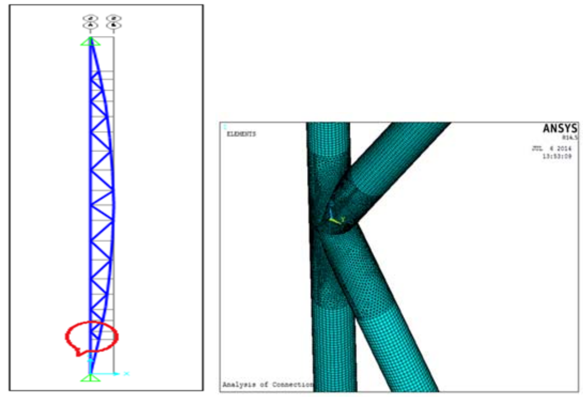

Fig. 5: Critical Joint Considered for analysis and Meshing with SOLID185 and SOLID 186 in Ansys 14.5

5. RESULTS

Based on design from IS: 800:2007 following details of connections are further used for formulating the models for analysis of connections. Angle variation with minimum angle 30˚ is used for developing models along with 45˚and 60˚ as variation in angle usually used for trusses. Also, variation in vertical distance (s) is done for all models (Refer Fig. 6,7,8,9,10,11,12,13,14,15,16,17)

Table 1 Geometrical Details of Connection

Geometry of chord		Geometry of Brace -1		Geometry of brace-2	
Diameter of chord	Thickness of chord	Diameter of brace 1	Thickness of brace 1	Diameter of brace 2	Thickness of brace-2
60mm	3.6mm	60mm	3.6mm	60mm	3.6mm

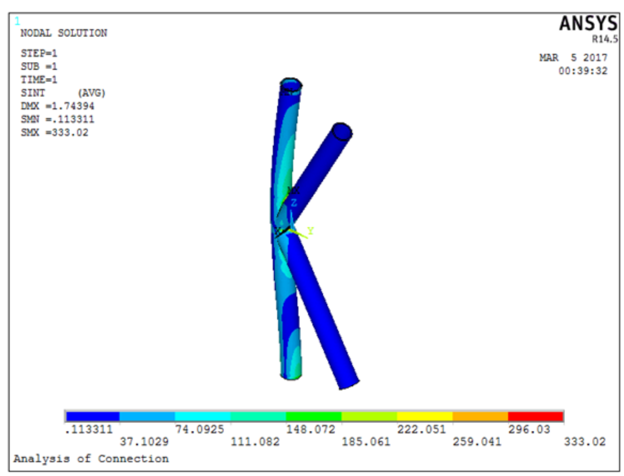

Fig. 6: Analysis of X-Connection with θ= 30˚ (s=0mm and p =152.27mm)

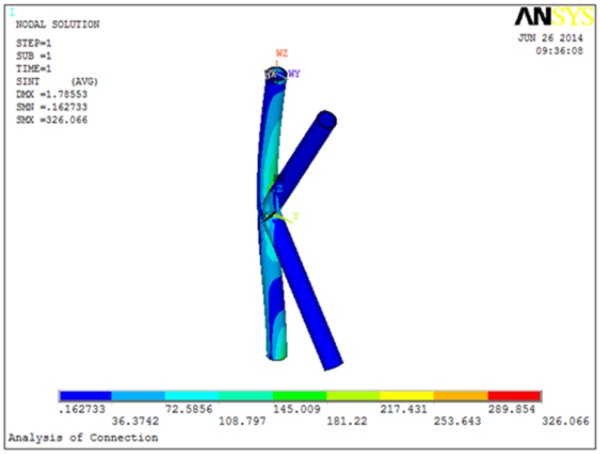

Fig. 7: Analysis of X-connection with θ = 30˚ (x = 5mm and p = 144.13mm)

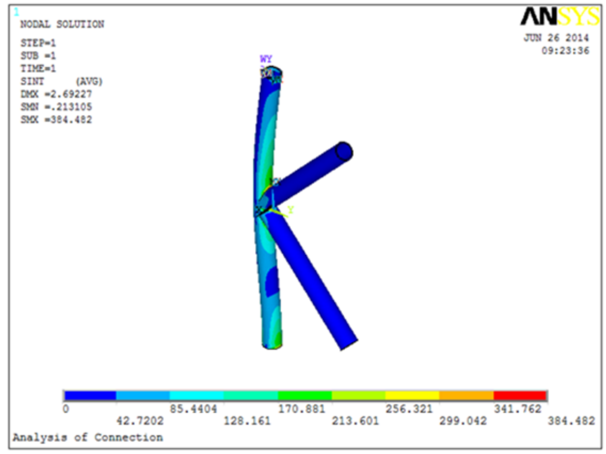

Fig. 10: Analysis of X-Connection with θ= 45˚ (s=0mm and p =75.23mm)

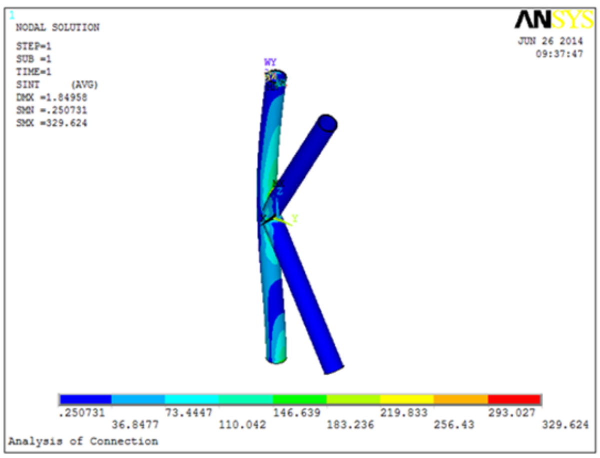

Fig. 8: Analysis of X-Connection with θ= 30˚ (s=10mm and p =117.63mm)

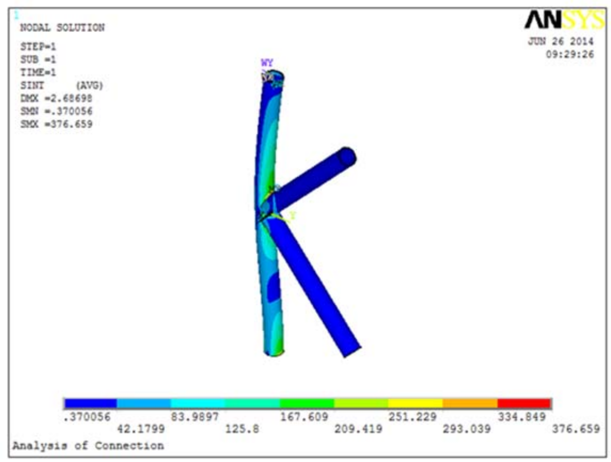

Fig. 11: Analysis of X-Connection with θ= 45˚ (s=5mm and p =90.38mm)

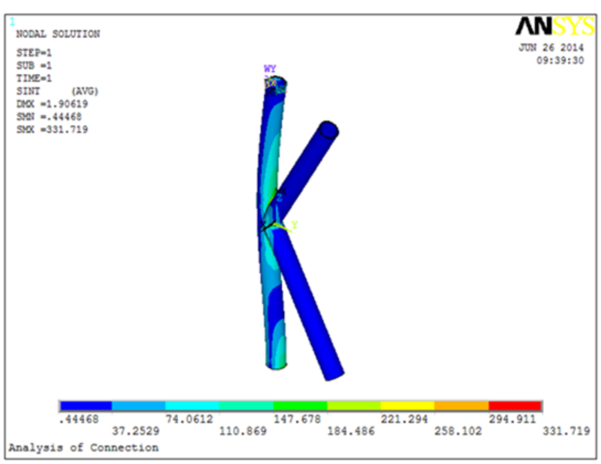

Fig. 9: Analysis of X-Connection with θ= 30˚ (s=15mm and p =109.15mm)

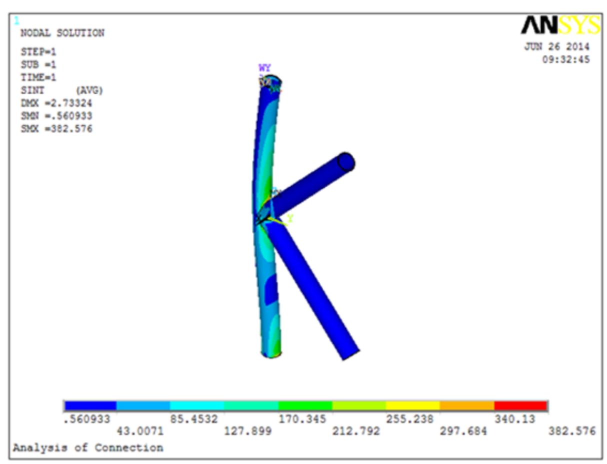

Fig. 12: Analysis of X-Connection with θ= 45˚ (s=10mm and p =75.23mm)

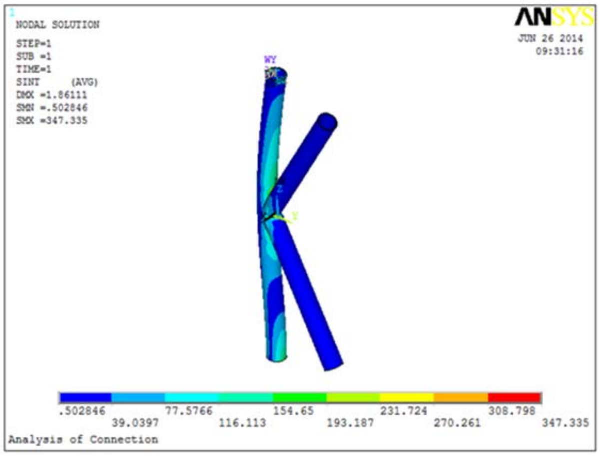

Fig. 13: Analysis of X-Connection with θ= 45˚ (s=15mm and p =70.30mm)

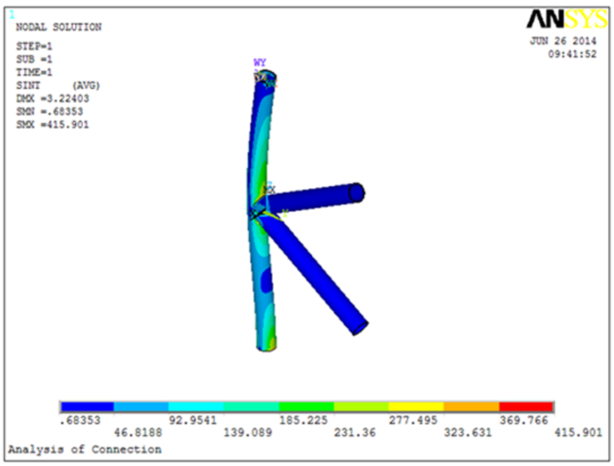

Fig. 14: Analysis of X-Connection with θ= 60˚ (s=0mm and p =65.13mm)

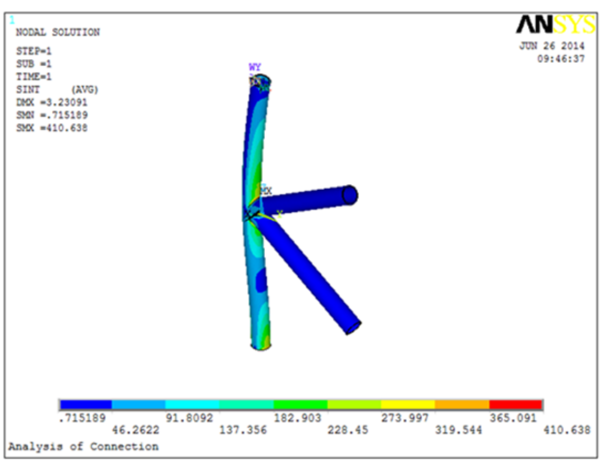

Fig. 15: Analysis of X-Connection with θ= 60˚ (s=5mm and p =62.29mm)

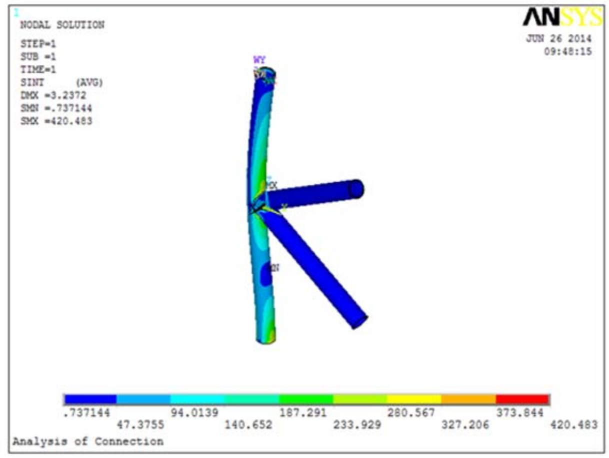

Fig. 16: Analysis of X-Connection with θ= 60˚ (s=10mm and p =53.68mm)

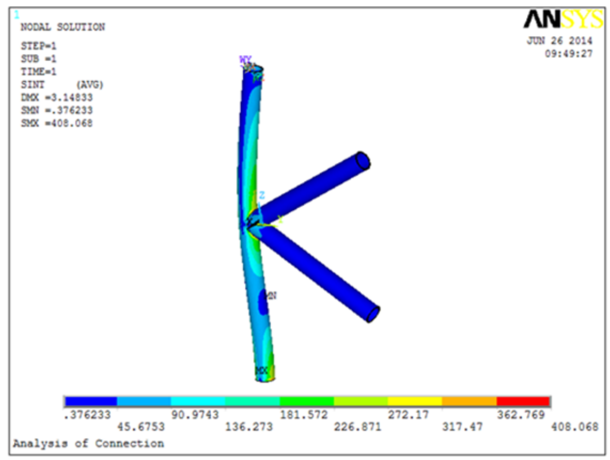

Fig. 17: Analysis of X-Connection with θ= 60˚ (s=15mm and p =50.79mm)

Table 2: Stress Values for X-connection with one end fixed and other end radial restrained.

Angle in degrees	Stress from Ansys in N/mm^2				
	s= 0mm	s= 5mm	s=10mm	s=15mm	Average Stress
30	333.02	326.066	329.624	331.719	330.1073
45	384.482	376.659	382.576	347.335	372.763
60	415.901	410.638	420.483	408.068	413.7725

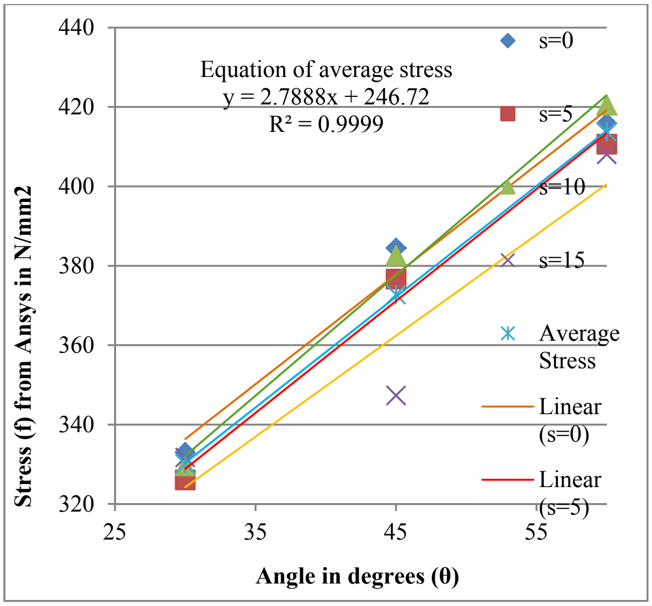

Fig. 18: Stress Vs angle for X connection with one end fixed and other end radial restrained.

6. CONCLUSION

1. Generalized stress intensity (f) equation is developed with variation in angle between chord and brace (θ)

   $f = 2.7888\theta + 246.72$

2. Angle less than 30˚ is not permissible as per Indian and International codes for tubular design so select angle in between 30 to 60˚ which gives moderate results in terms of stress.

3. If X-connections are developing avoid welding at the top surface with angle between chord and brace (θ) = 30˚ as it reduces stresses. If welding on top surface is unavoidable due to some circumstances then modify angle. (θ >30˚)

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