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Finite Element Analysis of X-type Uni-planer Tubular Connections for Structural Glazing Support System

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Abstract—*Use of structural glazing is very popular now-a-days in commercial buildings like multiplexes, shopping malls, theatres, etc. Support system in the form of vertical trusses, Horizontal trusses, Bowstring with strut profiles is generally used. Members popularly used for such system are tubular (Rectangular Hollow Sections, Circular Hollow Sections).Failure of tubular connections may lead to failure in the form of slippage of structural glazing panel and hence need attention. This paper mainly concentrates on the analysis of X-type of circular tubular connections. For this, two profiles (Warren, Parabolic) of trusses are analyzed with variation in height from 4m to 24m. Further the circular tubular connections are analyzed using finite element analysis and compared with available international codes such as American Welding Society-AWS (2010), CIDECT (2008), China code GBJ-88, 1989, Euro code 3-Design of steel structures (2005) and Indian code IS: 806:1968. The interaction curve for change in stresses at the joint with both ends of chord fixed and with variation in angle between axes of tubular member is plotted and a generalized equation for stresses is suggested. Also, general design guidelines are suggested for tubular connections under Indian conditions.*

Keywords*: Structural Glazing Support System, Circular Tubular Connection, International Code, Ansys models, Interaction curve.*

1. INTRODUCTION

Recently it is observed that use of structural glazing panels is becoming popular in commercial contemporary buildings like shopping malls, theatres, airports due to its aesthetic appearance. The aim is to achieve maximum transparency and to provide aesthetic appearance. There are various glazing panels available in the market as per requirement which includes laminated glass, spandrel glass, annealed glass, heat treated glass etc. It is observed that connection of glazing panels is in the form of spider connections at regular intervals at the edges of panels. The support system provided to these panels ranges from glass supported, steel supported and tension rod systems. However steel truss system to be useful for larger heights and spans due to the advantages of steel and its versatile nature. Use of tubular trusses provides elegant appearance with aesthetic expression to building. Also, use of tubular sections is the first choice for engineers and architects due to its strength, fabrication ease and pleasant appearance. Tubular sections are available as Rectangular hollow sections and Circular hollow sections. Design of connection should be given importance as failure of connection may lead to reason for accident. This paper discusses the Circular tubular section analysis by using Finite element method.

Some important definitions: (Fig.1)

Chord: The bottom most tube of generally larger diameter, to which other tubes are connected.

Brace: The connecting tube to chord is known as brace. It is generally of lesser diameter than chord.

Tubular connections are classified as Rectangular Hollow sections (RHS) and Circular Hollow Sections with the no of planes involved i.e uni-planer and multi-planer connections. In this paper, Hollow Uni-planer circular overlap K- connections are considered for analysis. Failure modes of connections are Chord face failure, chord side failure, chord shear failure, punching shear failure, local buckling, and brace failure with reduced width.

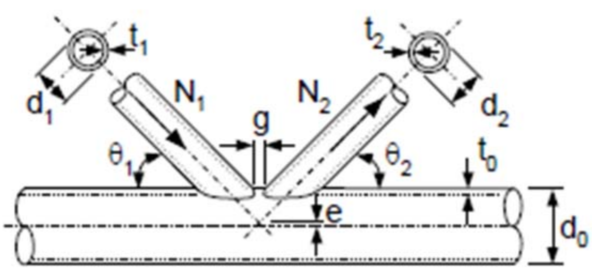

Fig. 1 Terms in tubular gap joint [17]

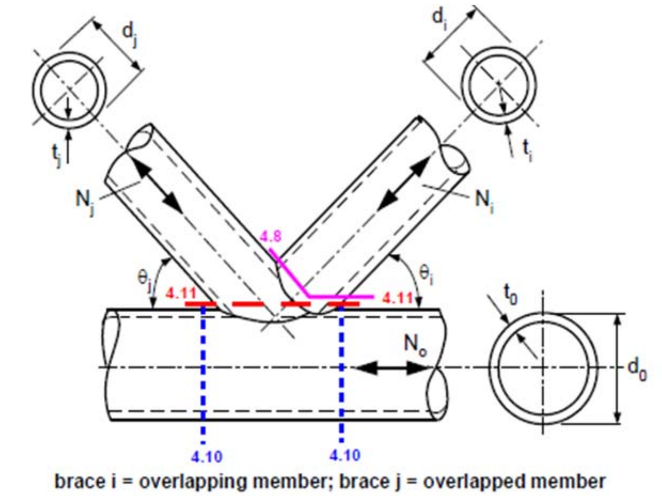

Fig. 2 Terms in tubular overlap joint [17]

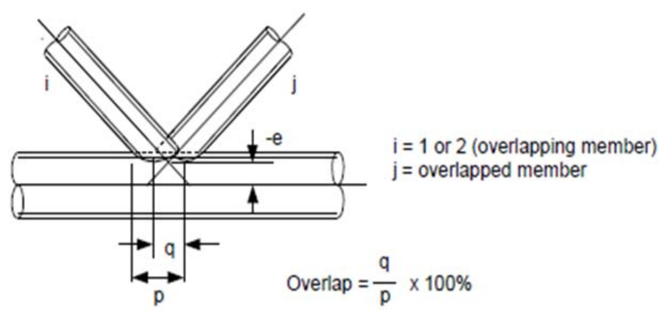

Fig. 3 Definition of efficiency in tubular joint [17]

2. LITERATURE REVIEW

Joint Considerations for Tubular members: [17]

In tubular joints efficiency plays very important role. Efficiency is nothing but the joint resistance of the connection. Efficiency can be calculated by formula explained in Fig. N0.3 Joint considerations are divided into two groups as

- Tubular truss design: In this design of chord, brace are carried out using IS:800:2007
- Tubular Joint Design: For tubular joint design joint resistance must be calculated based on efficiency of joint as-
- When 25% ≤ O_v < 100% [17]

$N_i = f_{yi}.t_i \frac{\pi}{4}[2\, d_i + d_{ei} + d_{eov} - 4t_i]$

When O_v = 100% [17]

$N_i = f_{yi}.t_i \frac{\pi}{4}[2\, d_i + 2d_{eov} - 4t_i]$

where,

$d_{ei} = \frac{12\, f_{yo}.t_o}{{d_0}/{t_0}.f_{yi}\, t_i}.\, d_i \leq d_i$; $d_{eov} = \frac{12\, f_{yj}.t_j}{{d_j}/{t_j}.f_{yi}\, t_i}.\, d_i \leq d_i$

$d_{ej} = \frac{12\, f_{yo}.t_o}{{d_0}/{t_0}.f_{yi}\, t_i}.\, d_j \leq d_j$

For uni-planer X-joints, the use of weld effect makes little effect on joint strength. Therefore it is not required to model a weld for overlap X-connection. [18]

3. NATIONAL, INTERNATIONAL CODES AND PROVISIONS FOR TUBULAR CONNECTIONS

For tubular truss and tubular connections various national and International codes are available out of which few are discussed here include American Welding Society (AWS):2010, Comite International pour le development et l' Etude de la construction Tubulaire (CIDECT) Design guide for hollow circular sections: 2008, Euro code 3 Design of steel structures CEN: 2005, National Standard of the People's Republic of China code for design of steel structures GBJ17-88:1989, Indian Standard code of practice for use of steel tubes in general building construction IS: 806:1968

The minimum angle between axes of chord and brace specified in all codes is 30˚to avoid welding fabrication difficulties. AWS code is applicable only for High tension steel. Indian Standard code does not provide any provisions for tubular connections with respect to connection strength. CIDECT, Euro code and china code gives strength formulae based on the efficiency criteria.

4. PROBLEM FORMULATION

For problem formulation case studies of existing structural glazing system has been carried out considering profile system, centre to centre distance between two trusses , height, geometry, type of connections, material for glazing etc with the help of this problem is formulated as-

Building plan with dimension 67.5X 95m in plan with parabolic and Warren profile is considered. For variation in loading condition; height variation is considered starting from 4m, 8m, 12m, 16m, 20m, and 24m. Material for structural glazing of Poisson's ratio (μ) = 0.49, Modulus of Elasticity (E) = 1100kg/m^3. Steel is taken as mild steel with modulus of elasticity = 2X 10^5 N/mm^2 and Poisson's ratio = 0.3, type of connection X- uni-planer tubular connection. Analysis and design of this truss system is carried out in SAP2000.

5. NUMERICAL FORMULATION AND ANALYSIS

Numerical formulation has been carried out using Finite element analysis and it is sub- divided into following steps-

- Analysis of Truss system
- Design of tubular member
- Analysis of tubular connection

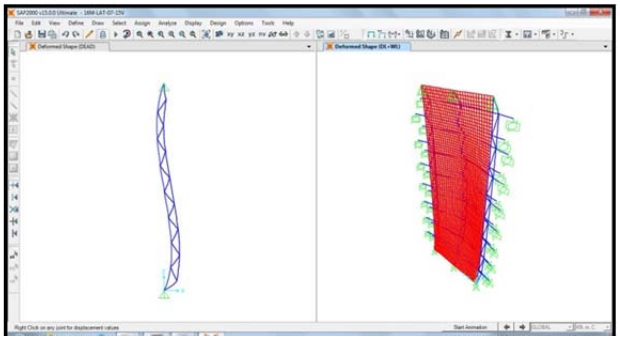

Fig. 4: Deformation of 16m Warren truss after analysis in SAP2000

such analysis and designs has been carried out for all profiles and are compared to get economical design. (Refer Table 1)

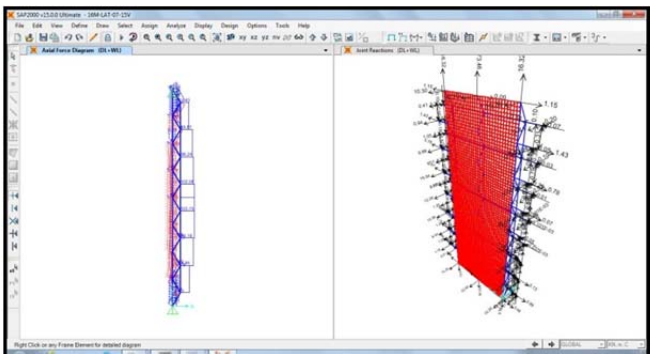

Fig. 5: Resultant forces in 16m Warren truss assembly after analysis in SAP2000

Table 1: Weight comparison of Structural glazing support system as per IS: 800:2007

Serial No.	Height in metre	Weight of Profile 1 in kN	Weight of Profile 2 in kN
1.	4	3.812	3.575
2.	8	6.242	6.839
3.	12	12.34	12.01
4.	16	21.335	30.216
5.	20	29.55	34.803
6.	24	35.585	39.94

For further analysis of tubular connection, designed members from SAP2000 are taken as- Diameter of Chord=60mm, Diameter of brace = 60mm, thickness of chord = 3.6mm, thickness of brace = 3.6mm, angle between brace and chord. 30˚, 45˚, 60˚, eccentricity from centre of chord above is (s) is taken as 0, 10, 20 and 30mm. Boundary condition is taken

For analysis of connection, finite element method of analysis is used. Ansys14.5 is used as a Finite element method tool to create models in which SOLID185 element is used. Boundary condition i.e. ends of chord fixed and braces free direction is considered with angle between axes of chord and brace from 30˚, 45˚, 60˚ and axes of brace meeting at distance of 0mm,

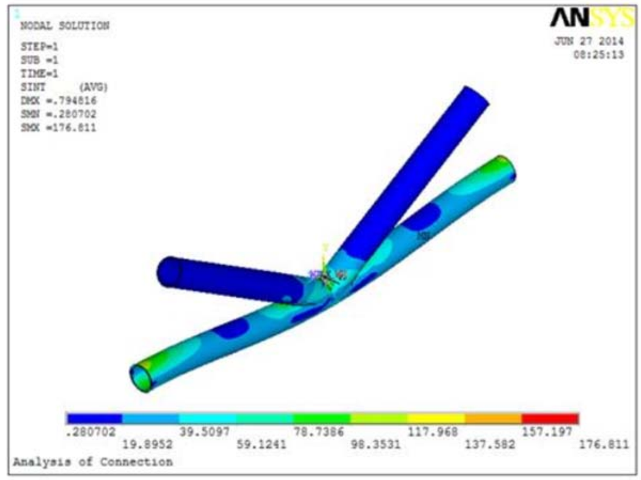

Fig. 6: Analysis of X-connection model for 24m with θ=30˚(s = 0 and q=152.27mm)

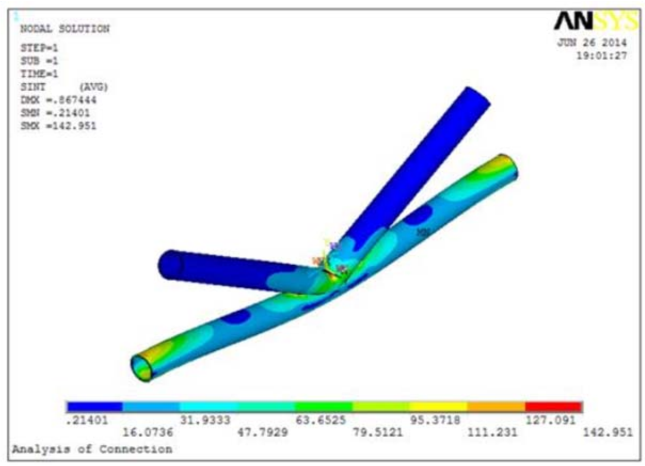

Fig. 7: Analysis of X- connection for 24m truss with θ=30˚ (s = 10mm and q= 117.23 mm)

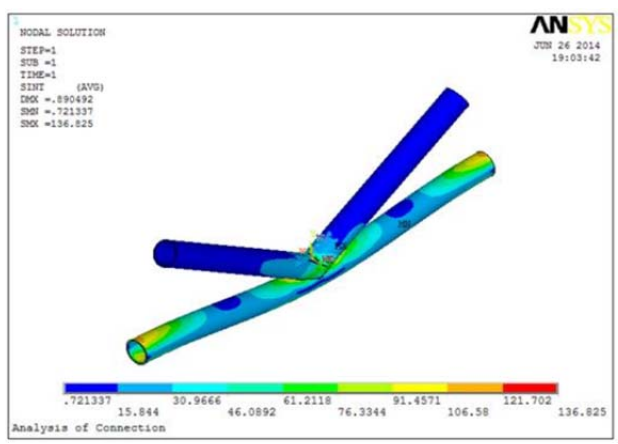

Fig. 8: Analysis of X- connection for 24m truss with θ=30˚ (s = 20mm and q= 89.99 mm)

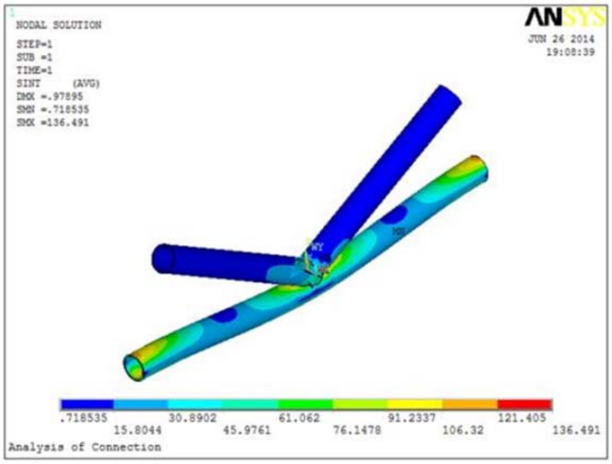

Fig. 9 Analysis of X Connection for 24m truss with θ=30˚ (s = 30 mm and q= 60.3 mm)

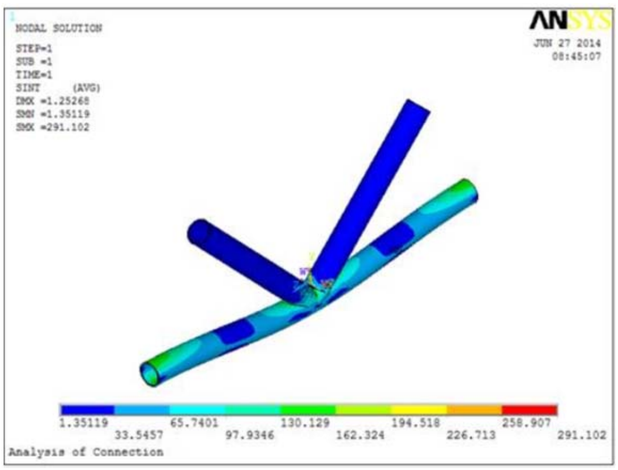

Fig. 10 Analysis of X- Connection for 24m truss with θ=45˚ (s = 0 mm and q= 60.3 mm)

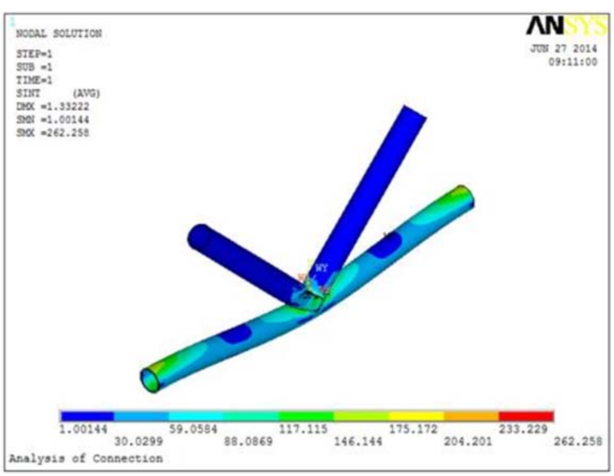

Fig. 11 Analysis of X-connection for θ =45˚ (s = 10 mm and q= 75.23 mm)

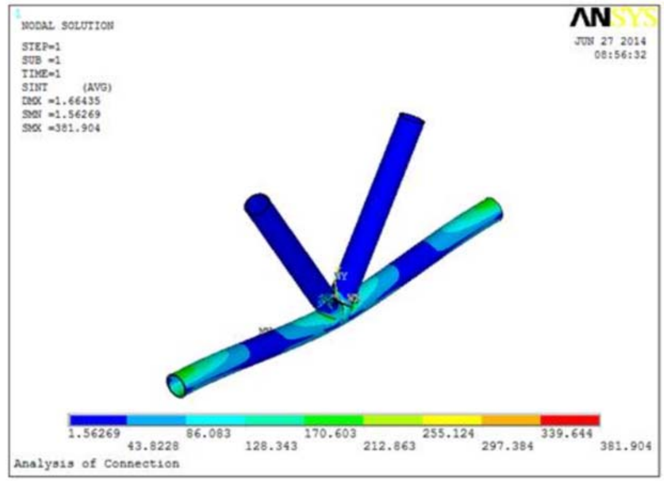

Fig. 12 Analysis of X-connection for θ = 60˚ (s = 0 and q = 65.13mm)

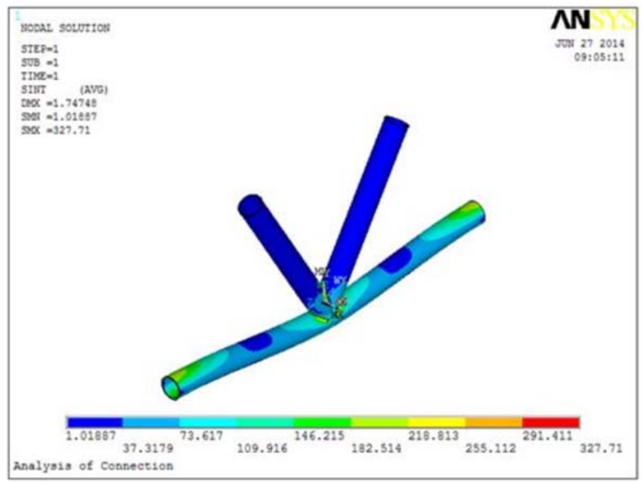

Fig. 13. Analysis of X- connection for θ = 60˚ (s= 10 mm and q = 53.68 mm)

10mm, 20mm, and 30mm above axis of chord. For meshing SOLID 186, SOLID 45 elements which are higher order 20-noded solid elements that exhibit quadratic displacement behavior used. (Refer Fig. No 6, 7, 8, 9, 10, 11, and 12)

To study the effect of horizontal gap between geometry of connection (p), here the change in the horizontal distance of the axes of braces (p) is also considered along with the vertical distance (s).

6. DISCUSSION

With the help of this analysis following observations are made and interaction curve is plotted considering height and weight for both truss profile systems parabolic and warren. (Refer Fig. 14)

As per all international codes which are studied here mention the importance of efficiency of the joint to be checked which is not available in the Indian standard code, therefore with CIDECT: 2008 code all efficiencies are calculated for X-connection.

Calculation of efficiency of joint:

$$O_v = \frac{q}{p} \text{ x } 100\%$$

$$= \frac{91.97}{152.27} \text{X}100$$

$$= 60.39\%$$

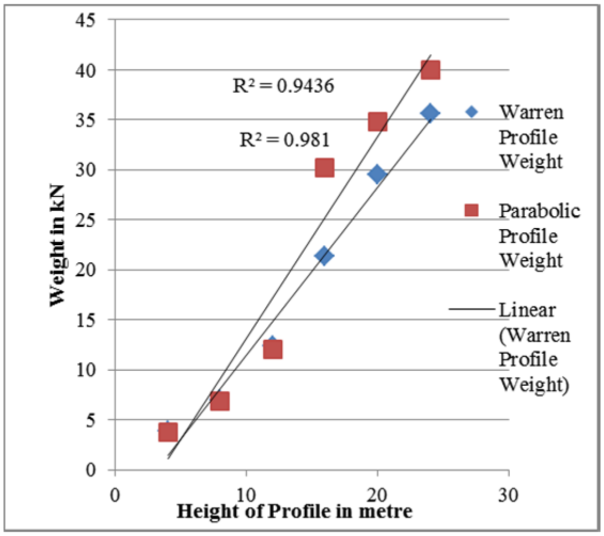

Fig. 14: Height Vs Weight of Support System Profiles

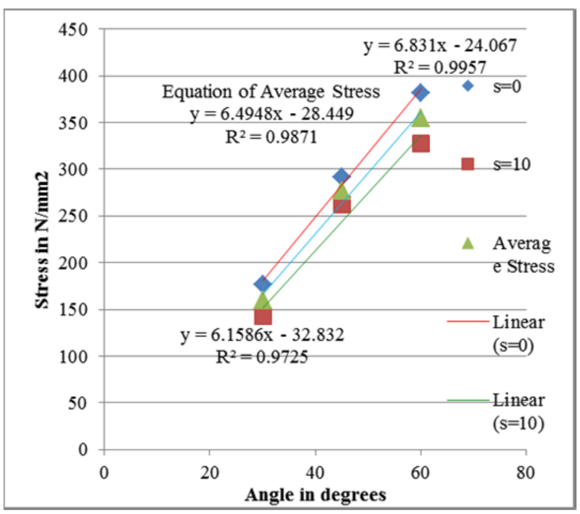

Fig. 16: Stress variation with s for θ = 30˚, 45˚ and 60

Calculation of axial force on tubular member-

$$d_{ei} = \frac{12\, f_{yo}.t_o}{d_o/t_o . f_{yi}\, t_i} . d_i \leq d_i$$

$$= \frac{12 \text{ X } 250\text{X}3.6}{60/3.6 \text{ X } 250 \text{ X}3.6} \text{X } 60$$

$$= 43.2\text{mm} < 60\text{mm}$$

$$d_{eov} = \frac{12\, f_{yj}.t_j}{d_j/t_j . f_{yi}\, t_i} . d_i \leq d_i$$

$$= \frac{12 \text{ X } 250\text{X}3.6}{60/3.6 \text{ X } 250 \text{ X}3.6} \text{X } 60$$

$$= 43.2\text{mm} < 60\text{mm}$$

$$25\% \leq O_v < 100\ \%$$

$$\text{so, } N_i = f_{yi}.t_i \frac{\pi}{4}[2\, d_i + d_{ei} + d_{eov} - 4t_i\,]$$

$$= 250 \text{ X } 3.6 \text{ X } \frac{\pi}{4}[2X60 + 43.2 + 43.2 - 4X3.6]$$

$$= 135.716 \text{ kN} > 9.685\text{kN}$$

Based on above study general design guidelines are suggested under Indian conditions for truss design and tubular joint design.

Design Guidelines:

- Truss design

1) Determine the truss layout, span, panel sizes, bracing type, geometry. Minimum angle between chord and brace (θ) must be equal 30˚ and maximum up to 60˚
2) Evaluate axial forces in all members
3) Determine member sizes of chord, brace etc. generally thickness of brace less than chord thickness
4) Check for deflections

- Joint Design

5) Layout the joints from fabrication point of view try for gap joints first.
6) Determine efficiency of joint based on the above mentioned formulae
7) Check for joint resistance (N_i > applied force(f)) if not modify the joint layout.
8) Design of weld

7. CONCLUSION

Based on the above study of tubular X-connection of structural glazing support system following conclusions are made and presented here as-

1) Warren Support system profile is economical than Parabolic profile when height of support system increases beyond 12m

2) Parabolic Profile may be used for lesser heights especially when aesthetic look is desired.

3) In case of X-tubular connections load carrying capacity increases with increase in angle up to 60˚.

4) In case of X-connections load carrying capacity decreases with increase in eccentricity (s). Therefore it should be preferred to match centroid of tubular members.

5) Generalized stress intensity (f) equation is developed with variation in angle (θ) between chord and brace for X-connection is-

$$f = 6.4948\theta - 28.449$$

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