

# Finite Element Analysis as a Research Method in Civil Engineering: A Case Study of K-Uni-planer Tubular Connections

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## Abstract

Finite element method is a powerful tool to solve complex problems related not only in engineering but almost in all fields of research. In structural engineering where critical analysis with accuracy is an important parameter, there it proves to be effective. This paper focuses on an application of finite element method of analysis for K-type tubular connections considering two different boundary conditions; one end fixed and other end of chord radial restrained, ends of chord fixed. Models are generated using Ansys 14.5 software as a tool. Efficiency of joint is also checked being an important parameter in analysis of tubular connections as per CIDECT: 2008 code. Further interaction curve is plotted for stress Vs angle of joint and generalized stress equation is suggested.

**Keywords:** Finite element analysis, tubular connections, Ansys models, Efficiency

## Introduction

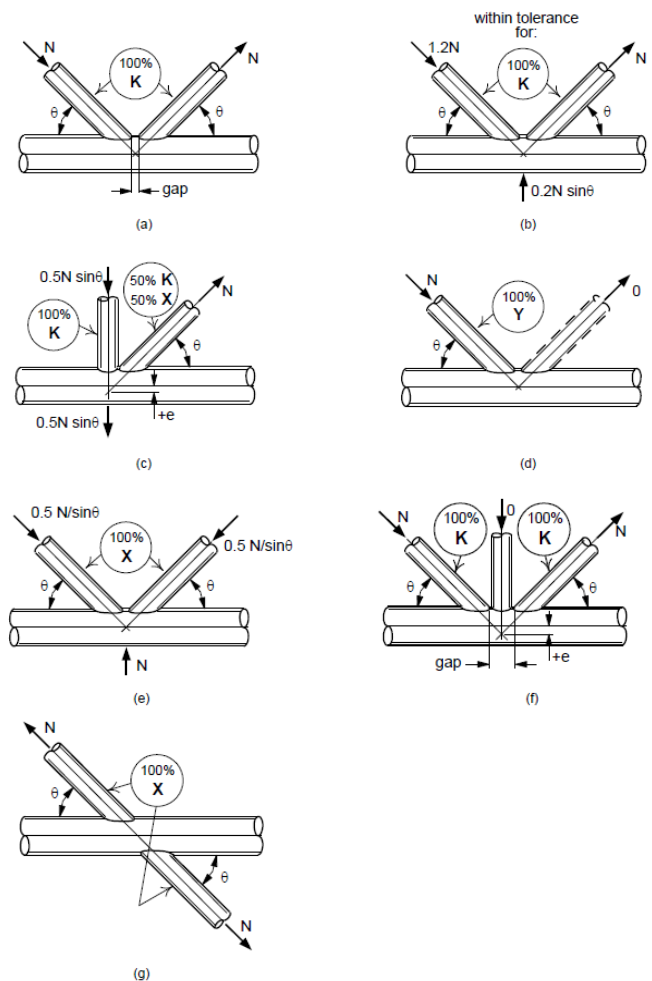
Recent development in structures all over the world in the form of using new forms, innovative materials makes it complex to analyze accurately. To overcome difficulties arising from such modern structures finite element analysis method proves to be useful in terms of accuracy. Finite element analysis involves following procedure-

- The given body subdivided into equivalent system of finite elements
- Suitable displacement function is chosen
- Element stiffness matrix is derived using variation principal of mechanics such as principal of minimum potential energy
- Global stiffness matrix of entire body is formulated
- The algebraic equations thus obtained are solved to determine unknown displacements
- Element strains and stresses are computed from the nodal displacements.

Connections are critical as they carry maximum load. Tubular steel Connections are popular due to their versatile nature and make a first choice for all structural engineers, architects.

## Types of Tubular Connection

Tubular connections are popular due to their versatile nature in terms of strength, aesthetic looks makes a first choice for architects and engineers. There are two types of tubular connections Rectangular Hollow Sections and Circular Hollow Sections depending upon its cross section but connections are also classified depending upon the nature of load acting on them. (Figure 1)



**Figure: 1** Classification of Tubular Connections [19]

## Literature Review:

Tubular connections are most popular now-a-days and development in these areas are considerable worldwide due to its structural advantages. Their advantages include high strength to weight ratio when subjected to particularly axial loads, their aesthetic advantages from architectural point of view., ease of maintenance ( due to less surface area to paint), less corrosion possibilities, their relatively high moment of area which helps to reduce buckling.[7]

Modeling techniques used in the finite element analyses of tubular joints for strength, stress fields and stress intensity factors. Guidance is given on model discretization, choice of elements, material curve input; weld modeling, result interpretation and limitations of using numerical technique.

Modes of failure are ultimate load and complete load deformation response. For joints with gaps, the bending stiffness of the chord wall has an appreciable effect on the overall joint behavior. 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. [17] There are various international codes available for design of tubular connection such as American welding society(AWS):2010, Comite International pour le Development et l'Etude de la construction Tubulaire (CIDECT::2008), Eurocode 3 Design of Steel Structures CEN : 2005, are studied and it is observed that all codes are over safe when design is taken into consideration. Hence need of revision of all international codes is not felt. [18]

### National and International codes for K-tubular connection design

Tubular connection design is based on two major design criteria which include- Static strength of joint and Fatigue strength of joint. For tubular connections there are various international and national codes available. out of which most used and referred codes for design are-

- American Welding Society (AWS),2010
- Comite Internatonal pour le Development et l'Étude de la Construction Tubulaire (CIDECT) Design Guide for Circular hollow sections 2008
- National Standard of People's republic of China code for Design of Steel structures GBJ17-88-1989
- Euro code 3 Design of Steel Structures CEN(2005)
- Indian Standard code of Practice for use of Steel tubes in general building construction IS: 806-1968

. In India there are very few guidelines available for geometry of tubular connection which includes-

- A weld connecting the end of one tube to the surface of another tube with their axes at an angle of not less than 30°
- Thickness of the tubes should not be less than 3.2mm for construction not exposed to weather, 5mm for structures not readily accessible for construction.
- Full penetration butt Weld should be used.

However, after detailed study of all above codes it is clear that CIDECT: 2008 code gives simplified design procedure and formulae to check efficiency and strength of K-tubular connections and therefore this code is followed here in this paper to check efficiency of the connection. The design value of capacity,  $N_c^p j$  of sub pipe in compression shall be calculated by following formula [19]

$$N_{cj}^p = \frac{12.12}{\sin \theta_c} \left[ \frac{d}{t} \right]^{0.2} \Psi_a \Psi_n \Psi_s t^2 f$$

$\Psi_a$  - parameter, calculated by the following formula:

$$\Psi_a = 1 + \left[ \frac{2.19}{1 + 7.5 \frac{a}{d}} \right] \left[ \left[ 1 - \frac{20.1}{6.6 + \frac{d}{t}} (1 - 0.77\beta) \right] \right]$$

The design value of capacity,  $N_c^p j$ , of the sub pipe in tension at joints shall be calculated by following formula,

$$N_{cj}^p = \frac{\sin \theta_e}{\sin \theta_i} N_c^p j$$

Efficiency of joint: [19]

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

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

- When  $O_v = 100\%$

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

where,

$$d_{ei} = \frac{12 f_{y0} \cdot t_0}{d_0 / t_0 \cdot f_{yi} t_i} \cdot d_i \leq d_i ; d_{eov} = \frac{12 f_{yj} \cdot t_j}{d_j / t_j \cdot f_{yi} t_i} \cdot d_i \leq d_i$$

$$d_{ej} = \frac{12 f_{y0} \cdot t_0}{d_0 / t_0 \cdot f_{yi} t_i} \cdot d_j \leq d_j$$

Meaning of the terms in formulae,

$N_c^p j$  = Design value of compressive capacity of the sub-pipe at a joint

$\Psi_a, \Psi_n, \Psi_s$  = Parameters for capacity calculation of directly welded pipe joints

$d$  = Diameter of sub-pipe

$t$  = Thickness of sub-pipe

$a$  = gap between two sub-pipes

$\beta$  = width ratio between brace/branch member(s) and chord

$O_v$  = Overlap = (p/q) X 100

$p$  = length of the projected contact area between the overlapping brace member and the chord, without the presence of overlapped member

$q$  = length of overlap between brace members of a K or N joint at a chord face

$N_i$  = joint resistance applied to member  $i$  ( $i = 0, 1, 2$  or  $3$ )

$t_i, t_j$  = thickness of hollow section member  $i$  or flange thickness of I section member,  $i$  ( $i = 0, 1, 2$ ) or  $j$  (overlapped brace)

$d_i, d_j$  = external diameter of a circular hollow section member  $i$  ( $i = 0, 1, 2$ ) or  $j$  (overlapped brace)

$d_{ei}, d_{eov}$  = functions used to describe the strength of K and N overlap joints

$f_{yi}, f_{yj}$  = yield stress of member  $i$  ( $i = 0, 1, 2$ ) or  $j$

$f_{y0}$  = yield stress of chord

$d_0$  = diameter of chord

$t_0$  = wall thickness of chord

### Problem Formulation

For study of tubular connection various case studies for commercial buildings has been carried out considering vertical truss system.. A vertical steel truss profile with variation of height from 4m,8m,10m,12m16m20m24m are considered with circular tubular connections Loads on vertical tubular trusses are analyzed with a combination of dead load, wind load which are supporting structural glazing panels for a shopping mall using SAP2000 as a tool. Design of circular tubular truss is diifrenciated in four categories-

- Compression members
- Tension members
- Inclined braces
- Beams

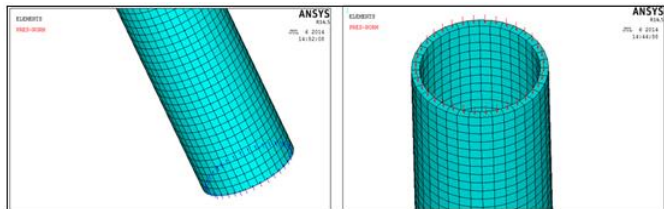
From above analysis most critically loaded joint is considered for further analysis of tubular connection based on the Indian standards as minimum angle between chord and brace is mentioned as 30°, so that is considered as a base value for angle and 45°, 60° are also considered to study behavior of connection under variation of angle. In addition to that vertical distance  $s$  is also varied and horizontal distance  $q$  is also varied for overlapped connection. Material used for

tubular connection is mild steel with modulus of elasticity ( $E$ ) =  $2 \times 10^5 \text{ N/mm}^2$ , Poisson's ratio ( $\mu$ ) = 0.3, type of connection K-Uni-planer circular tubular connection.

Analysis, design of tubular truss is carried out using IS: 806: 1968 and IS: 800-2007 as per IS: 875 (Part2)-1987 (Reaffirmed 2003) and IS: 1161: 1998, CIDECT: 2008 codes are used for design of connection.

### Numerical Formulation and Analysis

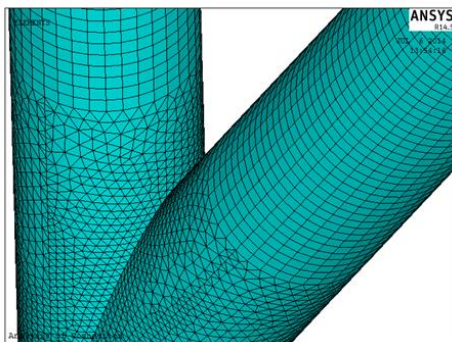
In this paper overlap K-tubular connections with boundary conditions as one end fixed and other end of chord radial restrained and ends of chords fixed. Loads are calculated from analysis of tubular truss in SAP2000 software which is further applied on chords and braces in the form of surface loads. (Fig. 2) Angle between chord and brace ( $\theta$ ) is taken as  $30^\circ, 45^\circ, 60^\circ$ , vertical distance between axis of braces is varied from 0,5,10,15mm, and horizontal distance between axis of braces ( $p$ ) is also varied.



**Figure: 2** Load applied on ANSYS model of K-tubular connection

Type element used for FEM-

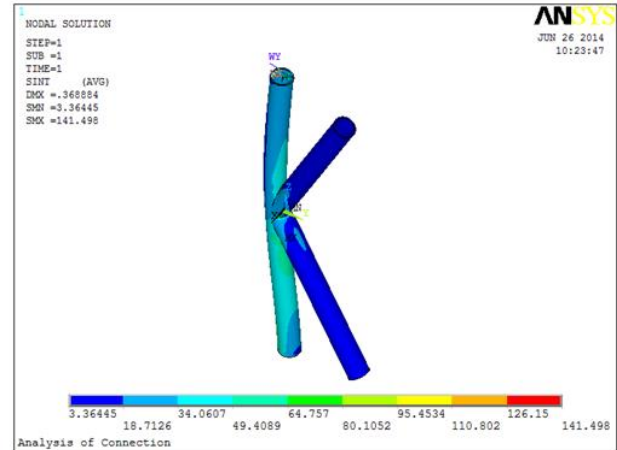
- SOLID185- It is used for 3D solid modelling of the structure. It is defined by eight nodes having three degrees of freedom at each node i.e. Translations in the nodal X, Y, and Z directions. The element has plasticity, hyper elasticity stress stiffening, creep, large deflections, and large strain capabilities. SOLID 185 elements are degenerated into brick, prism, tetrahedral to use in irregular regions.[19]
- SOLID186- 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 deflections, and large strain capabilities. It is basically suited for irregular meshes.[19]



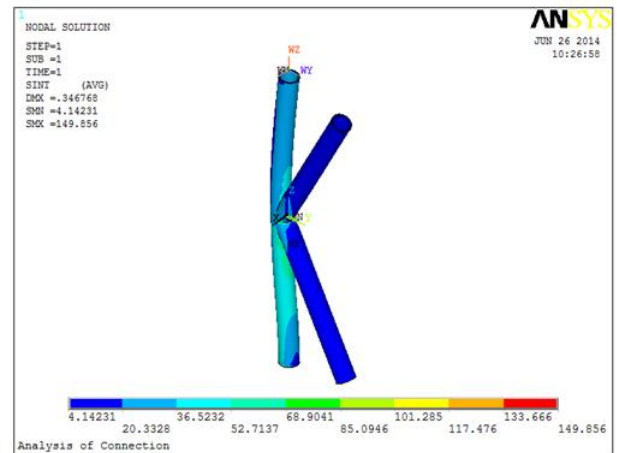
**Figure: 3** Meshing of connection model in ANSYS14.5 using SOLID185 and SOLID186 element

### Results

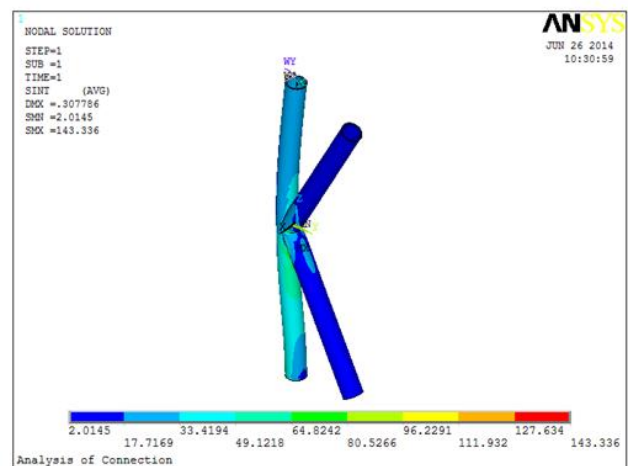
On the basis of above numerical formulation Ansys models for K-uni-planer connections are studied for its stress with variation in angle, horizontal distance between braces ( $q$ ) and vertical distance ( $s$ ) from centre of chord, following results are observed (Refer fig 4,5,6,7,8,9,10,11,12,13,14,15,16,) for first boundary condition one end of chord fixed other radial restrained.



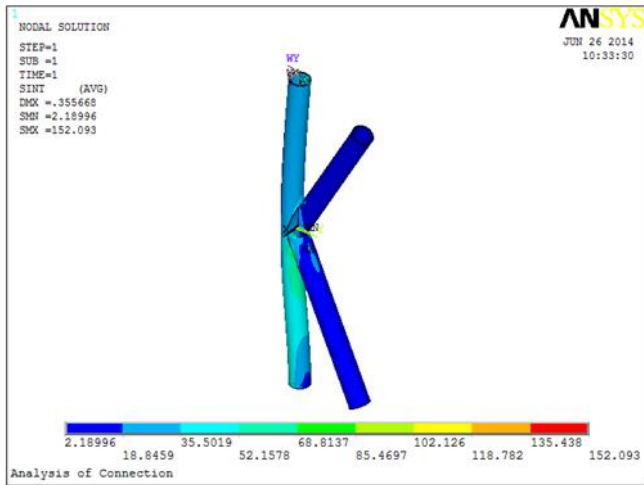
**Figure: 4** Analysis of K-type of connection with  $\theta = 30^\circ$  (with  $s=0$  and  $p=152.27\text{mm}$ )



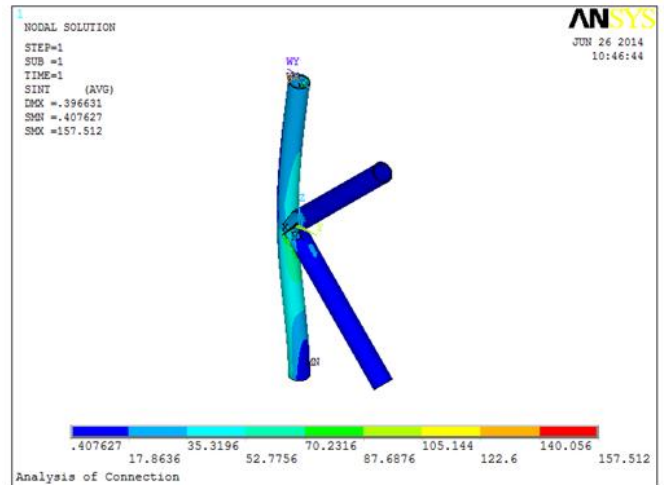
**Figure: 5** Analysis of K-type connection with  $\theta = 30^\circ$  (with  $s=5\text{mm}$  and  $p=144.13\text{mm}$ )



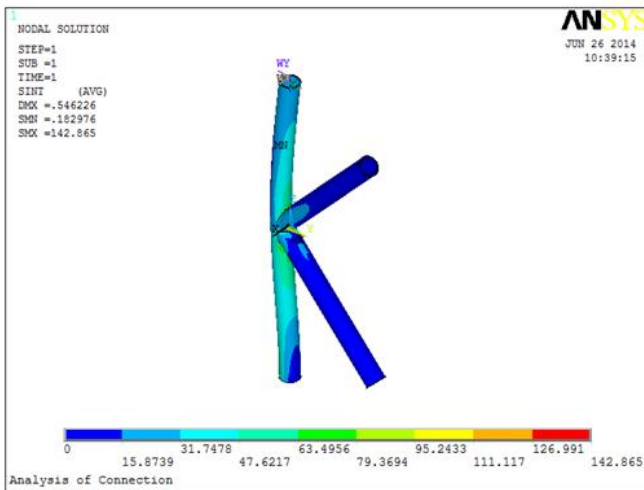
**Figure: 6** Analysis of K-type connection with  $\theta = 30^\circ$  ( $s = 10\text{mm}$  and  $p=117.63\text{mm}$ )



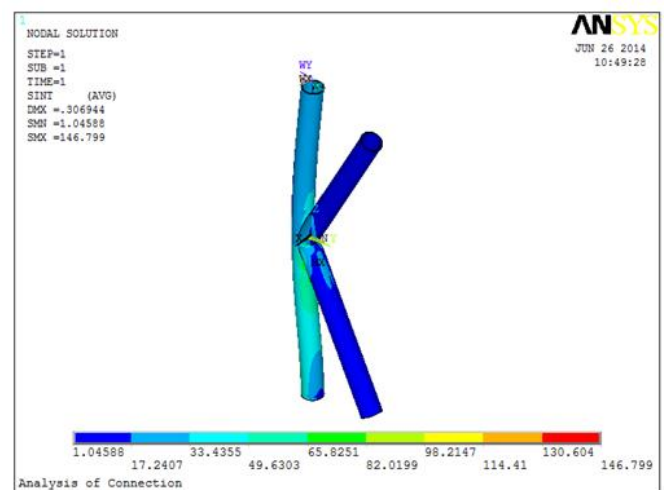
**Figure: 7** Analysis of K-type connection with  $\theta = 30^\circ$  (With  $s = 15\text{mm}$  and  $p = 109.15\text{mm}$ )



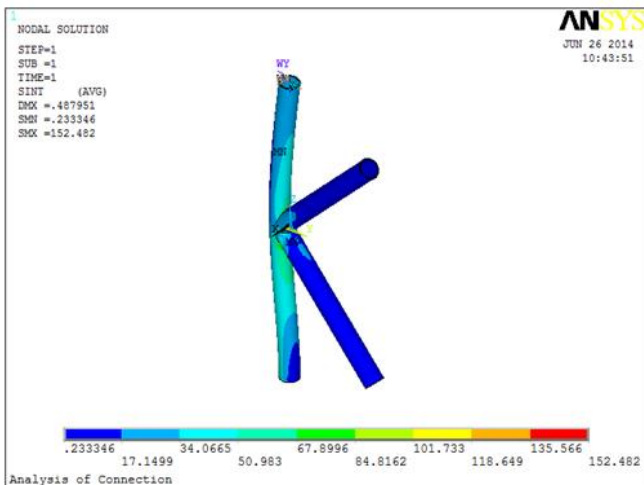
**Figure: 10** Analysis of K-type connection with  $\theta = 45^\circ$  ( $s = 10\text{mm}$  and  $p = 75.23\text{mm}$ )



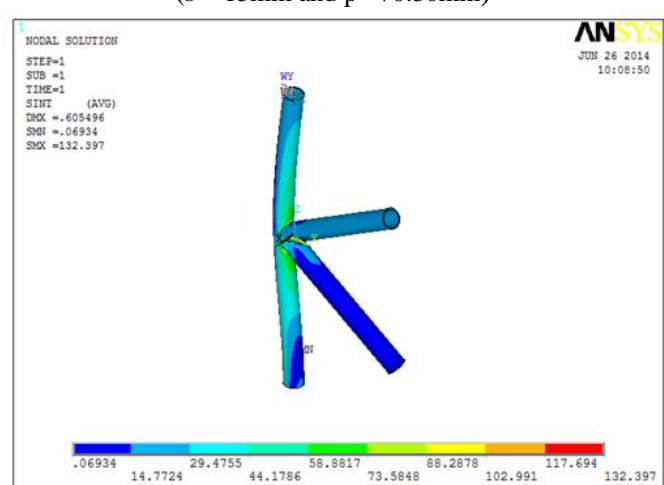
**Figure: 8** Analysis of connection K-type with  $\theta = 45^\circ$  (with  $s = 0\text{mm}$  and  $p = 95.23\text{mm}$ )



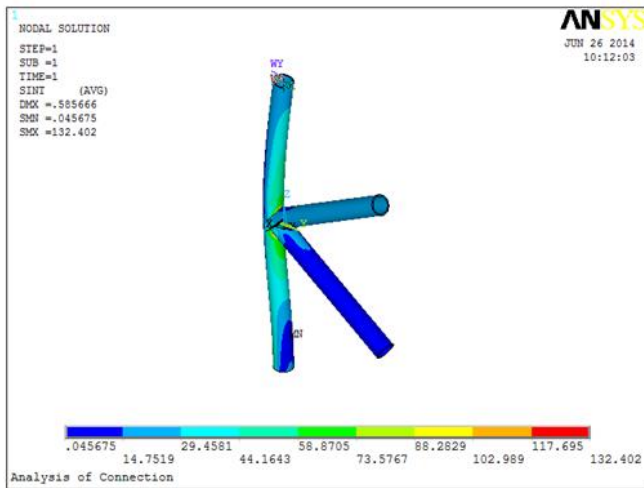
**Figure: 11** Analysis of K-type connection with  $\theta = 45^\circ$  ( $s = 15\text{mm}$  and  $p = 70.30\text{mm}$ )



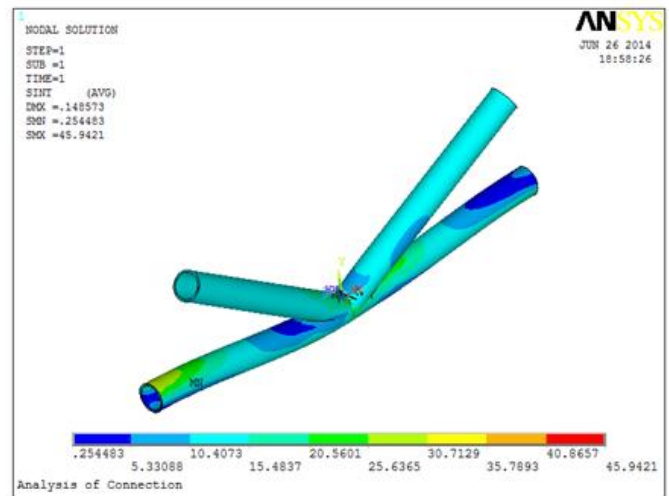
**Figure: 9** Analysis of K-type connection with  $\theta = 45^\circ$  ( $s = 5\text{mm}$  and  $p = 90.38\text{mm}$ )



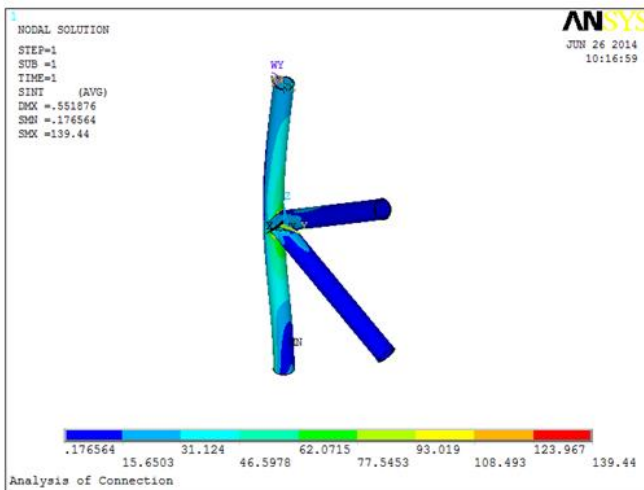
**Figure: 12** Analysis of connection K-type with  $\theta = 60^\circ$  ( $s = 0\text{mm}$  and  $p = 65.13\text{mm}$ )



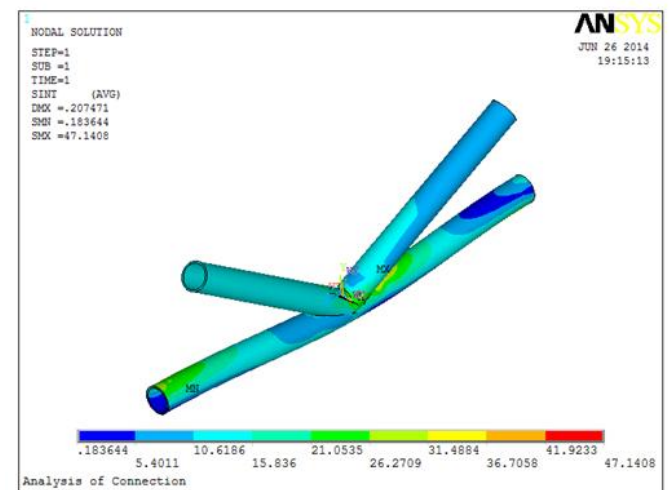
**Figure: 13** Analysis of connection K- type with  $\theta = 60^\circ$   
 ( $s = 5\text{mm}$  and  $p = 62.29\text{mm}$ )



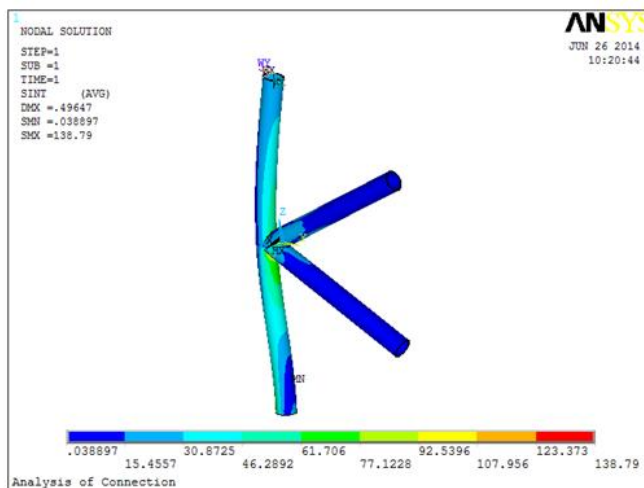
**Figure 16:** Analysis of K- connection with  $\theta = 30^\circ$   
 ( $s = 0\text{mm}$  and  $p = 152.27\text{mm}$ )



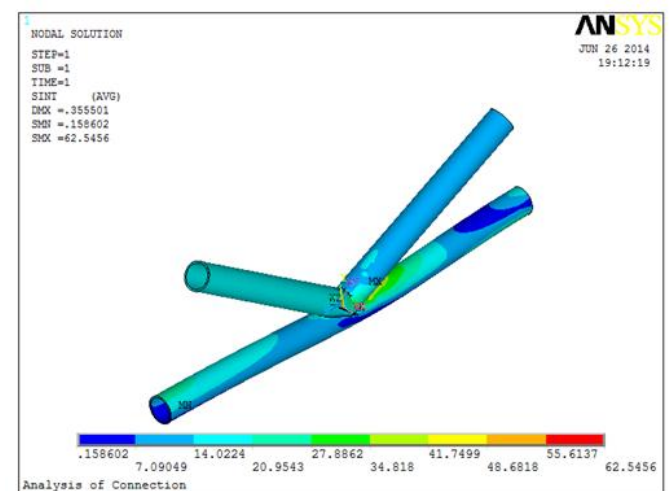
**Figure 14** Analysis of connections K-type with  $\theta = 60^\circ$   
 ( $s = 10\text{mm}$  and  $p = 53.68\text{mm}$ )



**Figure 17:** Analysis of K- connection with  $\theta = 30^\circ$   
 ( $s = 10\text{mm}$  and  $p = 117.23\text{mm}$ )

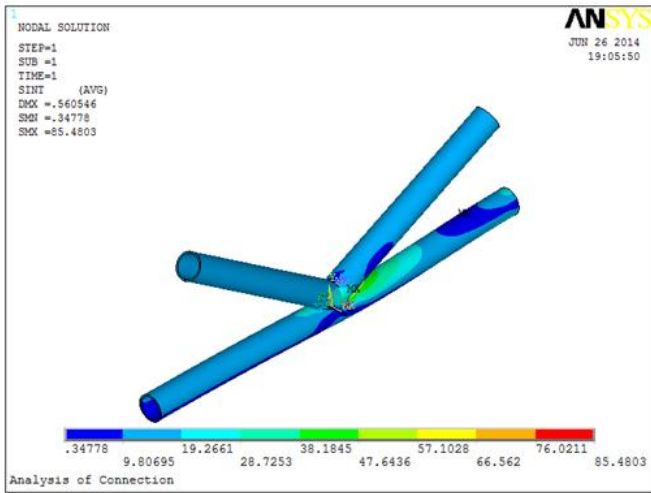


**Figure: 15** Analysis of connection K-type with  $\theta = 60^\circ$   
 ( $s = 15\text{mm}$  and  $p = 50.79\text{mm}$ ).

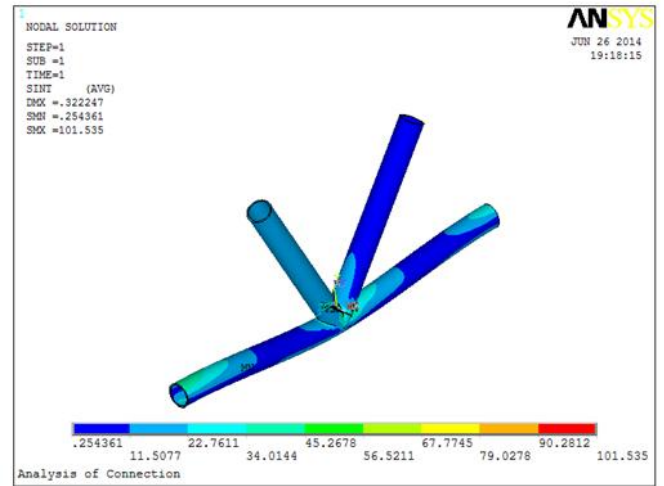


**Figure 18:** Analysis of K- connection with  $\theta = 30^\circ$   
 ( $s = 20\text{mm}$  and  $p = 89.99\text{mm}$ )

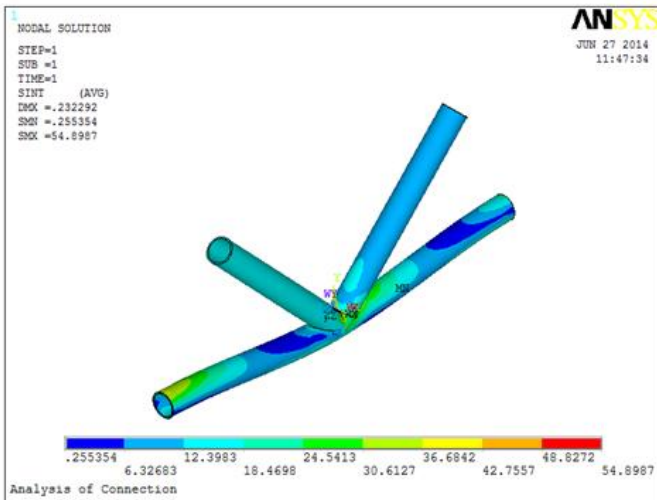
Similarly, K-circular tubular connections with second boundary condition that is ends of chord fixed is analyzed keeping loads, geometry, material properties same as that of previous case are analyzed for stresses (Refer figure 16, 17, 18, 19, 20, 21, 22,23) here, variation in the vertical distance is



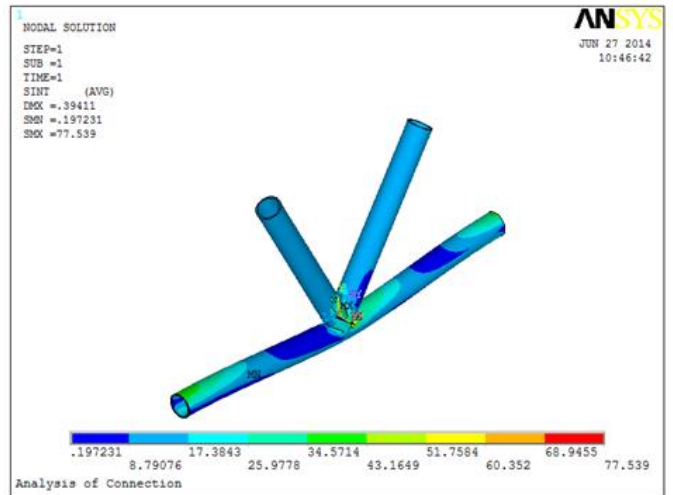
**Figure 19:** Analysis of K- connection with  $\theta = 30^\circ$   
 ( $s = 30\text{mm}$  and  $p = 60.3\text{mm}$ )



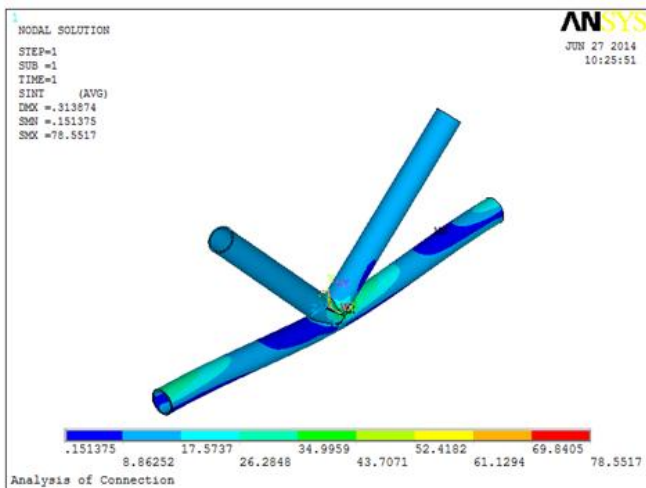
**Figure 22:** Analysis of K- connection with  $\theta = 60^\circ$   
 ( $s = 0\text{mm}$  and  $p = 65.13\text{mm}$ )



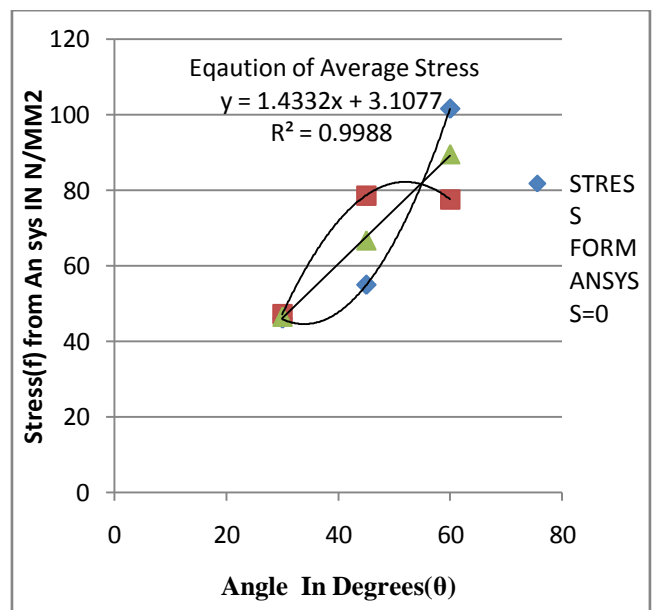
**Figure 20:** Analysis of K- connection with  $\theta = 45^\circ$   
 ( $s=0$  and  $p = 95.23\text{mm}$ )



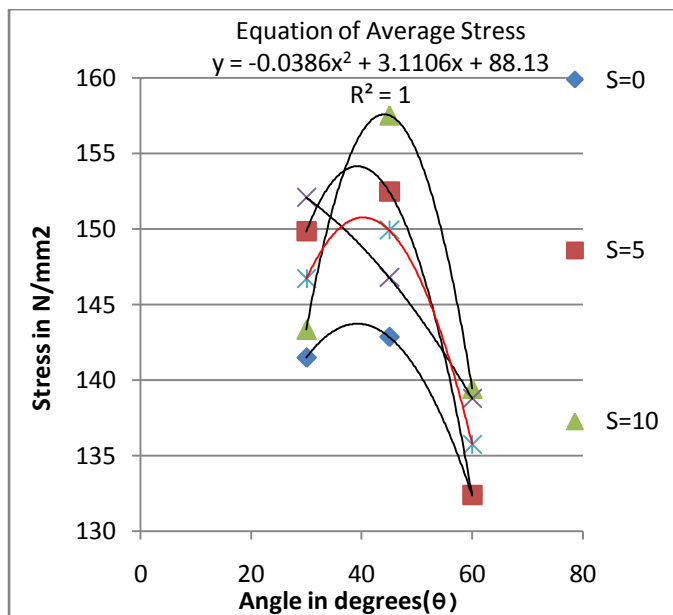
**Figure 23:** Analysis of K-connection with  $\theta = 60^\circ$   
 ( $s = 10\text{mm}$  and  $p = 53.68\text{mm}$ )



**Figure 21:** Analysis of K- connection with  $\theta = 45^\circ$   
 ( $s = 10\text{mm}$  and  $p = 75.23\text{mm}$ )



**Graph: 1** Stress Vs Angle ( $\theta$ ) for K-connection with both ends fixed



**Graph: 2** Stress Vs Angle ( $\theta$ ) for K-type of connection with one end fixed and other end radial restrained

Interaction curves are plotted for both the boundary condition cases (Refer Graph 1 and 2)

Efficiency being an important parameter in the study of tubular connection design, here all designed connections is checked for efficiency. Efficiency less than 25% should be rejected/ redesigned in terms of geometry (i.e. p, q)

**Table 1:** Efficiency of K-connection

Angle in degree ( $\theta$ )	s in mm	q in mm	p in mm	Stress in N/mm <sup>2</sup> for both ends fixed	Stress in N/mm <sup>2</sup> for one end fixed and other end radial restrained	Efficiency of Joint
30	s=0	91.97	152.27	45.942	141.498	60.40%
	s=10	57.33	117.63	47.1408	143.336	48.74%
	s=20	22.69	82.99	62.5456	--	27.23%
	s=30	0	60.3	85.48	--	0.00%
30	s=0	91.97	152.27	45.942	141.498	60.40%
45	s=0	52.8	95.23	54.898	142.865	55.44%
60	s=0	30.48	65.13	101.535	132.397	46.80%

30	s=5	75.7	144.13	--	149.856	52.52%
45	s=5	43.11	90.38	--	152.4821	47.70%
60	s=5	24.81	62.29	--	132.402	39.82%
30	s=10	57.33	117.63	47.1408	143.336	48.73%
45	s=10	32.8	75.23	78.55	157.512	43.60%
60	s=10	19.01	53.68	77.539	139.44	35.41%
30	s=15	40.38	109.15	--	152.093	37%
45	s=15	22.95	70.30	--	146.799	32.64%
60	s=15	13.24	50.79	--	133.79	26.07%

### Discussion

Based on the results of a comprehensive assessment it was found that efficiency is an important parameter in the design of tubular connections and need to be considered further in the design of weld. It was found that the load carrying capacity of connection increases with increase in angle between brace and chord up to 60 giving satisfactory efficiency (greater than 25%) which is acceptable as per CIDECT: 2008.

### Conclusion

1. From all available code CIDECT: 2008 gives resolved design parameters for tubular connections. Also it focuses on check of efficiency of connection which proves to be an important parameter in design of weld hence needs to be studied in detail to incorporate in Indian codes.
2. Need to have design guidelines of tubular connection under Indian circumstances
3. Load carrying capacity of K- tubular connections increase with increase in eccentricity, up to angle between brace and chord ( $\theta$ )=45° and reduce for 60°. Therefore limit the angle up to 45° for K- connections.
4. Generalized stress intensity equation is developed with variation in angle between chord and brace for K-connection –
  - $f = 1.4332 \theta + 3.1077 \dots$  for both ends fixed
  - $f = -0.0386\theta^2 + 3.1106\theta + 88.13 \dots$  for one end fixed and other end radial restrained.

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