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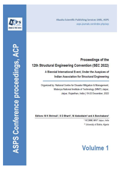

Moment Rotation behavior of Top and Seat Angle Connection with Angle Stiffeners

Navya Talla[1,*], K.Baskar[2]

[1] Department of civil engineering, M.Tech Student, National Institute of Technology, Tiruchirappalli, 620015, India
[2]Department of Civil Engineering, Professor, National Institute Technology, Tiruchirappalli, 620015, India

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Abstract

The design specifications for seven commonly used semi-rigid steel connections have been embodied in Indian Standard Code of Practice for General Construction in Steel (IS800:2007). Bolted connections are proved to be efficient by several researchers for its energy dissipating capability under reversal of loading; among them top and seat angle (TSA) connection has higher capacity. An attempt has been made to investigate the behaviour of stiffened TSA connection by finite element analysis in this research. Previously published experimental specimens of TSA connection (RAMAN 2005) semi-rigid TSA bolted connection and their results have been considered to develop 3D Non-linear Finite Element (FE) model and analyses have been executed using the general purpose FE software. The M-Θ_r behavior of numerical analyses are compared with that of the experimental results and thus, the FE model is validated. Further studies are carried out on TSA with all angles stiffened and TSA with angles subjected to tension alone are stiffened. The FE analysis results showed that TSA connection with only tension angles stiffened behave similar to that of TSA connection with all angles stiffened i.e., the stiffeners provided in compression angles does not contribute to the stiffness and connection capacity. The plastic flexural resistance of stiffened TSA connection has enhanced by 30% to that of TSA connection and the ratio of initial stiffness of stiffened TSA to the unstiffened TSA is found to be 1.25. So, the stiffened TSA connection is proved to be efficient in terms of both capacity and failure. The further studies have been carried out to investigate the influence of stiffener properties on the M-Θ_r mechanism of the connection and the results showed that thickness of stiffener equal to the beam web thickness is more efficient.

Keywords: Frye-Morris polynomial model; Top and seat-angle connection; Semi-rigid analysis; Moment relative rotation (M-Ɵr).

1. Introduction

Many members in a steel structure have to be coupled properly by means of fasteners, such that they act to bea single composite unit so as to facilitate the flow of forces and moments. A structure is solely as robust as its weakest link. If not designed and detailed properly, connections might become weaker compared to the members being connected. The assumption of ideally rigid or flexible does not represent the real connection behaviour, every connection behave in between rigid and flexible. There is a considerable gain in the research interest on semi-rigid connections due to the ease of installation and energy dissipating capability under reversal of loading. Moment-rotation relationships can be used in practicefor designers, so there is a necessity of generating an analytically reliable M-Ɵr behavior model for a type of connection to utilize it directly for analysis and design (Shen and Astaneh-Asl 1999 [17]; Elnashi et al. 1998 [15]; Garlock et al. 2003[16]; Cheol and Young 2007[18]).On understanding the importance of the semi rigid connections in design and analysis practice, AISC (2001, 2010), adopted TSA connections that transfers only beam-shear force on to the column into the design specifications. However, previous experimental results shows that in addition of transferring beam-shear force, TSA connection fairly transfers significant beam moment on to the column. From the pioneering of semi-rigid connections in steel structural design and analysis till now, various computational models have been proposed to establish M-Θ_r behaviour of semi-rigid connections. The simplest among those models were linear models (Monforton and Wu 1963[20]; Rathbun 1936[19]), but there were no significant improvements compared to the traditional connection models i.e., rigid and flexible. So, the linear models were very soon obscured with introduction of bilinear/piece-wise linear models (Tarpy and Cardinal 1981[21]; Jones et al. 1980[23], 1981[24]; Lui and Chen 1983[22]).Frye and Morris (1975) proposed the polynomial model by introducing constants of curve-fitting showed an appreciable improvement in contempt of the drawbacks of earlier models. Kishi and Chen (1990) has developed a three-parameter power model to determine M-Θ_r relation of the connection. Abdalla and Chen (1995) [11] expanded semi-rigid steel connection's database. A practical method for designing the partially restrained frames was proposed by Kim and Chen (1998). Acomputer-based analysis and design for designing semi-rigid steel frames including the flexibility effect of connection and geometric non-linearity

*Corresponding author. Tel: +917075549699; E-mail address: tallanavyagoud@gmail.com

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of members was proposed by Dhillon (1999) [10]. Yang et al.(2000) carried out FEA of double web-angle connections bolted to the column flange and welded to the beam web subjected to axial tensile loads, shear loads and their combination. Loads were monotonically increased and angle sections with three different thicknesses were analysed and determined that the angle thickness has an immense influence on the connection response. The methodology for moment-rotation response of PR connections modelling was presented by Citipitioglu et al., (2001) [9] and the effect of pretension and slip on the M-Θr behavior was studied. Kumuro et al., (2004) demonstrated a method of numerical analysis to evaluate the M-Θr relation of TSA connection under monotonic loading. The effect of angle dimensions connected to column web and the shear force on the M-Θr behavior was studied by Pirmoz et al., (2007) [8]. The influence of shear force on the connection initial stiffness was studied by Danesh et al., (2007) [7]. Yang and Lee (2007) investigated the M-Θr relation of double angle connection and two simple analytical models were proposed to predict the ultimate connection capacity and initial stiffness. The M-Θr behavior of the connection under combined effect of moment and axial force was studied by Pirmoz et al., (2008) [6]. Prabha et al., (2008) [5] has proposed a modified frye-Morris polynomial of top and seat-angle connection. The influence of seat angle stiffness on the M-Θr response of the TSA connection was studied by Pirmoz et al., (2009)[4]. Smitha and babu (2014) [3] showed that to predict the M-Θr behavior and failure modes finite element analysis can be used very effectively. Prabha et al., (2015) [2] has proposed an improved polynomial model for TSA connection with double web angles. Ali Ahmed (2017) [1] conducted research to examine the influence of prying force on the M-Θ_r behavior of the connection and proposed three failure mechanisms for TSA connection. From the literature it is observed that, various models like polynomial model, linear model, power model, two/three parametric model, etc., have been developed. Indian Structural Steel code (IS:800 2007) [14] has incorporated a simple polynomial model determined by Frye and Morris (1975) intended for designing semi-rigid frames. Frye-Morris polynomial model has the drawback that wide range of experimental data is required for evaluating the size parameter's exponent powers that influences the behavior of connection. Analytical simulations are generally preferred as experimental investigations are expensive and laborious. But, the basic analytical models of experimental studies need to be validated against experimental behavior. Neoteric advances in programming technique have led to the advancement and use of general purpose FEA software, which streamlines the problem. The validated analytical model could be used for simulation of number of costly experiments by differing the significant size parameters that affects the behavior of connection.

2. Previous Experimental Study

The real Moment-Rotation behavior of a connection can be predicted only through the experiments. The test setup of TSA connection (Raman 2005) is illustrated in Fig. 1. The experimental setup consists of two beams. Each beam is of 1.1m connected to a central stub column of 650mm height through top and seat angles using 16mm high strength friction grip bolts. A 214 Nm pre torque was used to tighten the bolts. The geometric details of the sections are presented in Table 1. Farther ends of beams were supported one on roller and the other on hinge to resemble a simply supported condition. The advantage of this setup is that the column displaces only vertically and does not rotate, so that theconnection deformation alone contribute to the relative rotation between column and beam. The strains are measured using strain gauge, which is pasted on the top/seat angle. Three dial gauges D1-D3 (Fig. 1) with a least count 0.001 mm are used to measure deflection. An inclinometer was used for measuring the beam-column relative rotation. The load is gradually applied over the centre of stub column at the top of the experimental specimen by means of hydraulic jack. Dial gauge readings, rotations of beams and strain gauge readings are observed at frequent intervals of load up to the collapse load. Two stages of behavior are identified before connection failure occurs. The stage I corresponds to the portion before air gap (shown in Fig. 2) closure and the stage II after the closure of air gap and before failure. Initially the load is carried by the tension of the seat angle beam flange leg and the top angle beam flange leg bolts experience shear. The top angle beam flange leg bolts fail in shear. In stage II, the load is carried due to the action of compressive thrust of the beam on the flange of column and the tension by the bolts in the seat angle column flange leg. On further loading, the seat angle beam flange leg yields. Finally the plastic hinge is formed in the seat angle beam flange leg and it failed in tension. Photographic view of the tensile fracture failure mechanism is shown in Fig. 3.

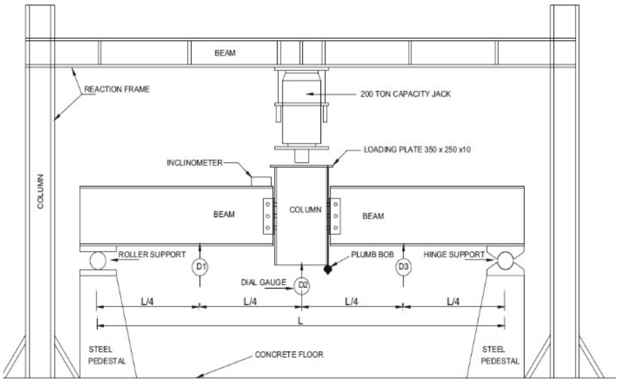
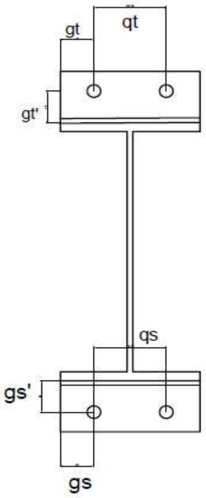


Fig.1 Test setup and instrumentation
(Prabha et al; 2008)

Table 1 Dimensions of the experimental specimen

Section	Cross sectional dimensions (mm)	Length (mm)
Beams	UB 306.6 x 165.7 x 11.8 x 6.7 x 46.1	1100
column	UB 306.6 x 165.7 x 11.8 x 6.7 x 46.1	650
Top and Seat angle	ISA 65 x 65 x 6	165.7
Bolt	16	-



gt : 40 mm
gt’: 40 mm
gs: 40 mm
gs’: 40 mm
qt : 86.7 mm
qs : 86.7 mm
air gap : 10mm

Fig. 2. Geometric details of experimental specimen

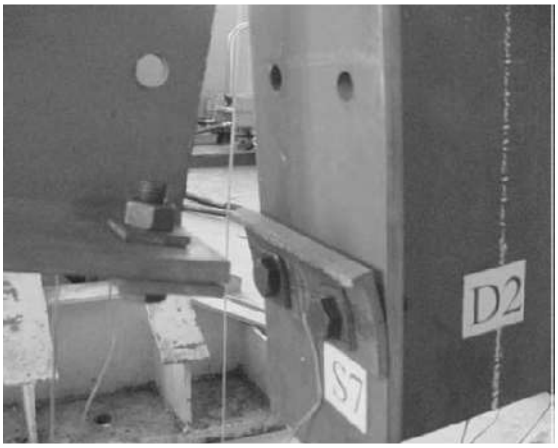


Fig. 3. Failure of connection

3. Numerical Modelling

The commercial displacement based finite element (FE) software (ABAQUS) has been used all through this work to find the behavior of connection. The geometric model consists of four parts such as beam, column, angle and bolt. The model consists of two beams of 1.1m each connected to the flange of column, the height of the column is 650mm. Angle sections of length equal to the width of beam are used. Class 8.816 mm diameter HSFG bolts were used for the connection. Each part of the assembly is modelled using continuum eight-noded solid elements with reduced integration (C3D8R), the element is defined by eight nodes having three degrees of freedom at each node between beam and column a10 mm air gapis considered. Hexagonal bolt heads and nuts are idealized as circular bolt heads and nuts and the fillets in the angles are not modelled to avoid sophistication in the model. The material is considered as isotropic and homogenous. In the existent study, the properties of material like poisons ratio, young’s modulus, yield stress and ultimate stress considered are given in the Table.2 are taken from the experimental investigation carried out by Raman 2005.

Stress – strain relationship of steel is illustrated by a tri-linear constitutive model. The material model for beams, column, angles and bolts are shown in Fig. 5.

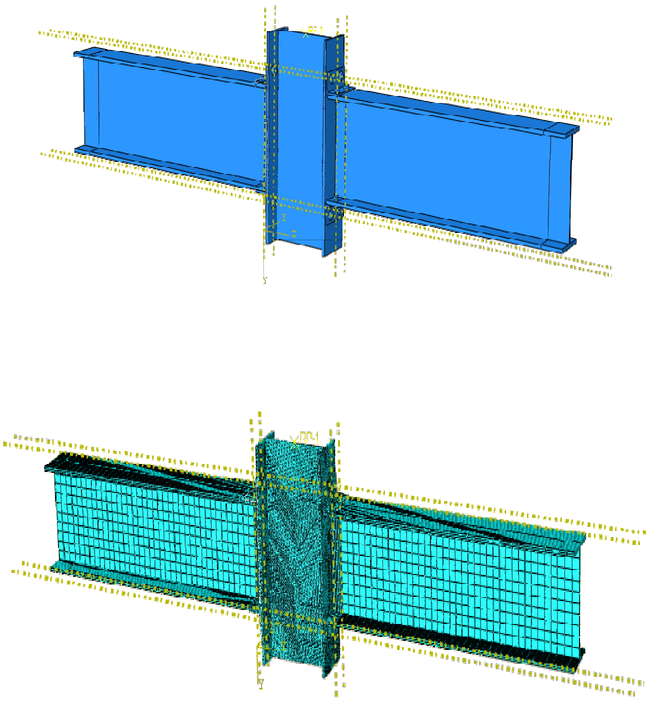
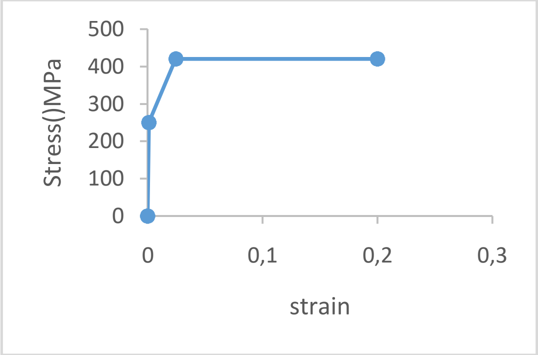
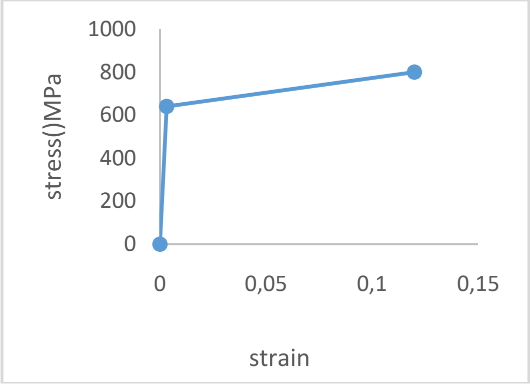


Fig. 4. Top and seat angle connection



Stress-strain curve for a) Beam, angle and column



b) bolt

Fig.5.Material Model

Table 2.Material properties

Connecting members	Young's modulus (Gpa)	Poisson's ratio	Yield strength (MPa)	Ultimate strength (MPa)	% elongation
Beam, column, angle and stiffener	200	0.3	250	420	0.2
Bolt	200	0.3	640	800	0.12

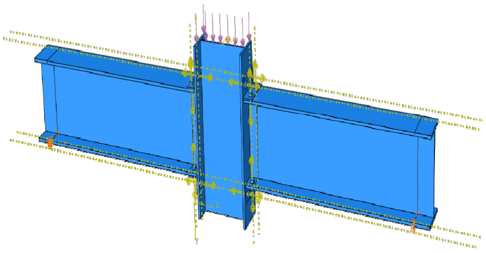


Fig. 6. Loading and boundary conditions.

Damage properties have been introduced to the material. The strain rate of 0.001 is used, fracture strain is used accordingly, displacement at failure is taken as 0.21(Fracture strain is defined as the strain at the onset of failure and the displacement at failure is defined as the difference between the strain at the ultimate stress and the failure strain times the characteristic length).

One end of the two beams is connected on either side of the flanges of the vertical column with top and seat angles. The other ends of the beams are supported, one on hinge (Ux=0, Uy=0, Uz=0) and theother on a roller (Uy=0, Uz=0) to simulate a simply supported condition. Themodel isanalysed in two steps. Bolt pretension force of 73200 N is applied to the bolt shank which is equivalent to the experimental pre torque of 214 Nm. On the top of column Uniform pressure load is applied. Arrangement of the final finite element mesh is determined based on the computing time, converegence of solution, refinement of mesh is implemented near corners, holes and the angles, where stress concentration is anticipated to occur.

The transfer of forces is through friction due to clamping between the members caused by the pre-tensioning of the bolts. Contact between all the parts are explicitly modelled. The contact areas in the model are the top angles and seat angles to the beam flange/column flange, bolt holes to bolt shank and bolt heads to components. The interaction amongst surfaces in contact comprises of two components, one normal and the other tangential to the surfaces. The angle portion/column flange in contact with the bolt head is assumed to be hard introducing a tie constraint between them. The tangential contact is modelled using penalty stiffness formulation with a friction value of 0.3.

4. Validation of Finite Element Model

The comparison of the finite element analysis (FEA) with that of experimental results is made by comparing the failure mode, deformation and stress distribution and the Moment-rotation behavior of connection. In the experiment the seat angle has undergone tearing failure. The deformed configuration of the TSA connection by FEA at the ultimate stage is shown in Fig. 6. The failure mode of the FE model is correlated with the experimental failure mode in Fig. 7. The mode of failure observed in the ABAQUS finite element model and experiment is found to be similar.

5. Moment-Rotation behavior of Top and Seat angle connection.

The moment connections behavior is typically represented by the M-ϴr curve that illustrates the relationship between the applied moment (M) and the relative rotation between the beam and column (ϴr). The M-ϴr curve obtained from the FE analysis and experimental studies are compared in Fig. 8. The connection moment (M) is determined by multiplying the distance between supporting point of beam end and the instantaneous centre of rotation and reaction force. The relative rotation of the connection is evaluated by equation,

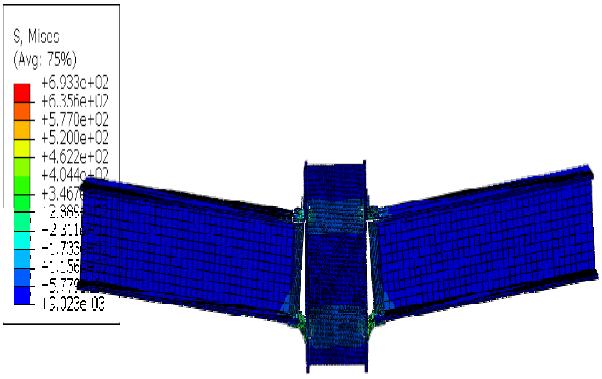


Fig. 6. Deformation and stress distribution of connection.

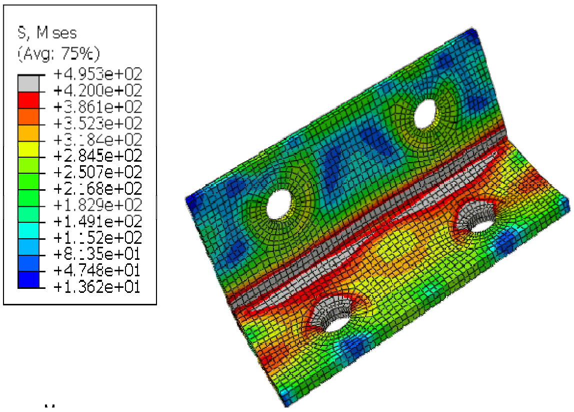


Fig. 7. Mode of failure of connection

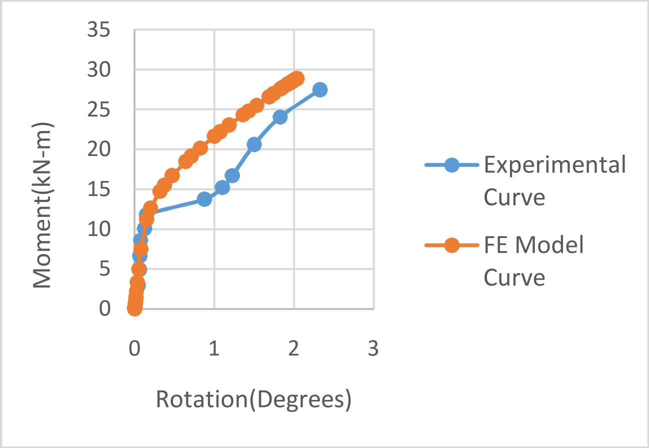


Fig. 8. Comparison of moment-rotation behavior of experimental and FE model.

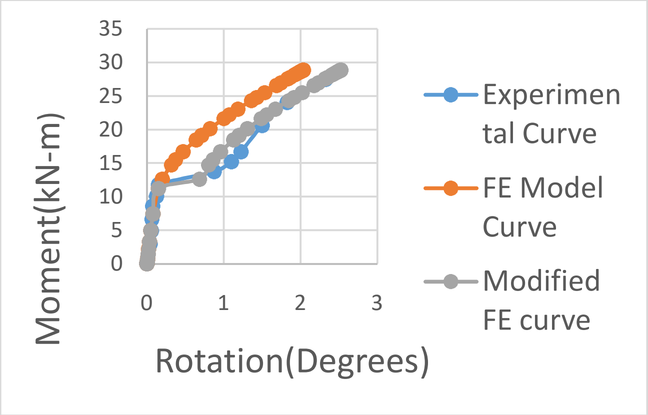


Fig. 9. Comparison of moment-rotation behavior of experimental and modified FE model

$$\theta r = \frac{(\ \delta b - \delta t)}{depth\ of\ beam}$$

Where δb and δt are the horizontal displacements at the face of the beam. In Fig. 8 it is seen that the experimental curve and the FE model curve compare well up to the shear fracture of the bolts connected to the top beam (in the experiment). The divergence in the ultimate moment capacity between the experimental results and FE analysis is 5%. The flat region in the experimental curve is due to the bolt fracture in the compression side of the connection. In the case of FE model analysis curve this bolt fracture phenomenon is not seen as the present ABAQUS finite element model could not capture it. Since it is known that in the first stage shear of the top bolt causes a displacement (slip) and the closing of the air gap, this displacement is added to the results of the FE model and the modified curve is shown in Fig. 9 and this modified results establishes a good correlation with the experimental results. As the mode of failure and the failure load agree reasonably well, this model was used for further investigation.

It is observed that the failure of the connection is due to the yielding of seat angle, so any improvement in the angles might enhance the connection capacity. Stiffening of angle can improve the connection behavior to a great extent.

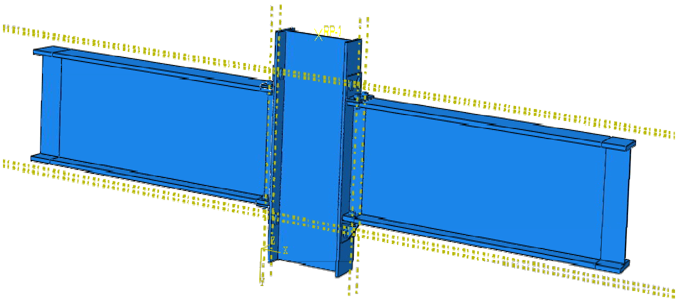


Fig. 10. TSA connection with only tension angles stiffened.

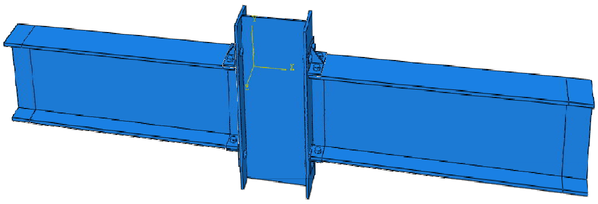


Fig. 11. TSA connection with all angles stiffened

Further studies are carried out on connection one with all the angles stiffened shown in Fig. 11 and the other with only angles in tension are stiffened shown in Fig. 10. Tie constraint has been introduced between stiffener and angle.

In the FE model the failure mode in two models is observed to be similar, the higher stress pattern is observed near the stiffeners which indicates weld failure is shown in Fig. 12

The M-ϴr behavior of unstiffened TSA, TSA with all angles stiffened and TSA with only tension angles stiffened are shown in Fig. 13.

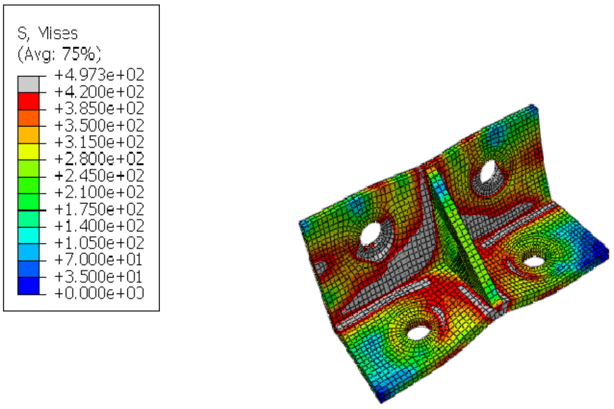


Fig. 12. Failure of Stiffened TSA connection

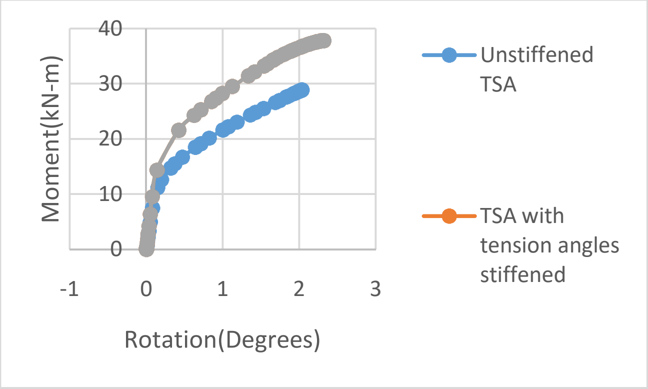


Fig. 13. Comparison of moment-rotation behavior of unstiffened TSA connection, TSA connection with all angles stiffened and TSA connection with only tension angles stiffened

It can be observed from Fig. 13 that the TSA connection with tension angles stiffened behave similarly to the TSA connection with all angles stiffened. This means that the stiffeners provided in compression angles does not contribute to the connection capacity and stiffness. It is seen from Fig. 13 that the behavior of all the three connections studied is similar till 0.14 degrees and later stiffened angles showed an improved behavior i.e., the TSA with stiffeners connection has enhanced plastic moment carrying capacity and stiffness compared to unstiffened TSA connection. The plastic flexural resistance has enhanced by 30% compared to TSA connection. The initial stiffness of the unstiffened TSA connection is found to be 105.7 kN-m/deg, the initial stiffness of the TSA with angles stiffened is 132.71 kN-m/deg. The ratio is found to be 1.25. So the TSA connection with only tension angles stiffened is proved to beefficient in improving the moment capacity and stiffness of the connection and can be used for further studies.

6. Effect of stiffener thickness

The effect of stiffener thickness on the M-Ɵr behavior of the connection is shown in Fig. 14. The initial stiffness of the connection remains invariable up to 0.070 rotation. The ultimate capacity of the connection has increased as the thickness of the stiffener increased but it is negligible. From the curve it is seen that there is no effect of change in thickness of stiffener on the connection's behavior and a thickness of stiffener equal to the beam web thickness is proved to be sufficient in increasing the efficiency of the connection.

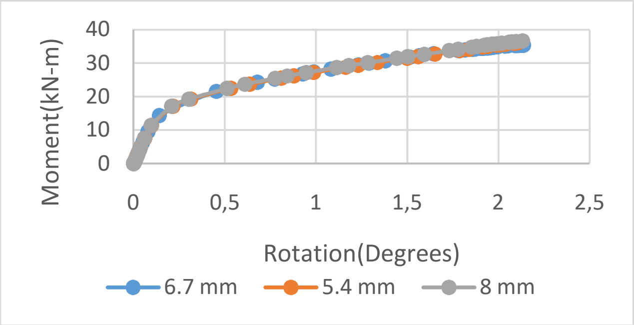


Fig. 14. Effect of stiffener thickness

7. Conclusions

A systematic numerical validation of experimental TSA connection (RAMAN 2005) is carried out using ABAQUS software. Based on the numerical analysis, the deviation in ultimate moment capacity between FE analysis and experimental results is about 4.5% for TSA connection. As the mode of failure and the failure load matches reasonably well, this model is used for further studies by adding stiffeners to the angles with angles stiffened only in tension and angles stiffened in both tension and compression. From the FE analysis, the behavior of all the three connections studied is same till 0.073 degrees. The TSA connection stiffened only in the tension and the TSA connection stiffened in both tension and compression has similar behavior i.e., stiffeners in the compression zone of the connection did not contribute to the connection capacity and stiffness. The plastic flexural resistance of TSA connection with stiffeners in tension angles has enhanced by 30% compared to TSA connection without stiffeners. The ratio of initial stiffness of TSA connection with stiffeners in tension angles to TSA connection without stiffeners is found to be 1.25. Thus, the TSA connection with tension angles stiffened is proved to be effective in enhancing the capacity and stiffness of connection. The effect of thickness of stiffener on the behavior of connection is found to be negligible.

Disclosures

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