International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-6, March 2020

Behavior of Circular Hollow Sections Solid Flanged Splice

Ahmed M. Ibrahim , Tamer H. Radwan , Sherif A. Ibrahim , Abdelrahim K. Dessouki

Abstract*: As the use of circular hollow section (CHS) is growing due to its aesthetic shape, attention should be given to its connections. Splicing the CHS is essential for its use as long flexural member. This research investigates the behavior of flanged CHS splice under pure bending. A finite element study is conducted to investigate the behavior of flanged splice with eight bolts arrangement and three different diameters. The finite element model is verified against experimental results. It showed good agreement in terms of both ultimate moment and flexural stiffness. Three different modes of failures are observed and investigated. Generally, mode of failure depends on the thickness of the end plate. Results of different end plate thicknesses is presented and the transition thickness between different modes is determined.

Keywords: Bolted splice, Circular end plate, Circular hollow section, End plate connection, Moment connection, Spliced CHS

I. INTRODUCTION

One of the major research interests in steel structure is the end plate connections that can be used for beam-to-column connection or splicing long members. Moment connections for I-Beams have been investigated under different types of loading [1] by many researchers. Finite element models depicting different geometrical configurations are developed [2–5]. Hollow sections splices is also investigated either for square hollow section [6] or rectangular hollow section [7–9]. arrangements along the sides of the SHS, as well as another two specimens on the CHS splice with circular end plate and 8-bolts equally distributed along the circumference.

However, as the use of circular hollow section is growing, more comprehensive studies have to be set for its connections behavior. Wang et al [10] proposed a design procedure for the case of 8-bolt CHS splice under bending using T-stub analogy and yield line theory.

Manuscript received on March 15, 2020.
Revised Manuscript received on March 24, 2020.
Manuscript published on March 30, 2020.

* Correspondence Author

Ahmed M.Ibrahim* , PhD candidate , - Structural Engineering Department Ain Shams University., Egypt, PH-+201006886934. E-mail: a.mostafa@meg-consult.com

Tamer H.Radwan : Assistant Professor - Structural Engineering Department - Ain Shams University.

Sherif A.Ibrahim : Professor of Steel Structures and Bridges - Structural Engineering Department - Ain Shams University.

Abdelrahim K.Dessouki: Professor of Steel Structures and Bridges - Structural Engineering Department - Ain Shams University.

An undergoing experimental test program of three specimens is carried out to investigate the behavior of CHS solid splice connection with different end plate thicknesses. Three modes of failures are observed in the test specimens, where one specimen failed by bolt failure while the second one by end plate yielding and the third mode is a combination of the two modes (plastification occurs in the end plate accompanied by bolt failure). A Finite element model is constructed using ABAQUS finite element package [11] and verified with the experimental results for ultimate capacity, failure mode and deformations. It is verified within acceptable range for CHS splice.

In this research, the constructed finite element model is used to perform an extensive study on the end plate connection with eight bolts configuration and different end plate thicknesses.

II. FINITE ELEMENT STUDY

A. Connection geometrical parameters to be investigated

End plate thickness is the major factor in determining the behavior of the connection [12]. A wide range of end plate thicknesses are studied in this paper to give the true behavior of CHS splice under pure bending.

Nine different end plate thicknesses are studied with 8 ASTM A325M high strength bolts of M-12, M-16 and M-20. Bolts are distributed uniformly along the gauge line that is 50 mm offset from the center line of the CHS. Edge distance from the gauge line to the end of the endplate is constant in all models and equals to 50 mm as shown in Figure 1.

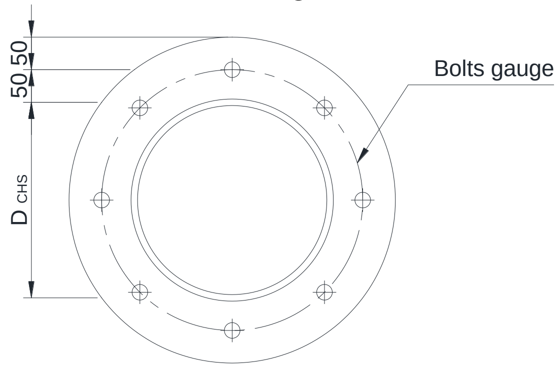

Fig. 1. Typical bolt configuration of solid circular plate connection

To thoroughly investigate the effect of end plate thickness on the behavior of the CHS, A diameter of 300 mm CHS is studied with nine different thicknesses of 6,8,10,12,16,20,24,32 and 40 mm.

Thickness of the CHS is taken equal to 12 mm to avoid any yielding in the CHS itself that may affect the results obtained from FE analysis.

B. Finite element model description

Finite element model constructed and verified in the prior experimental program [12] is used in this study but using different material models. The used material for CHS and end plates is S325JR. Bolts are modelled as A325M high strength bolts.

Materials of end plates and CHS are modelled as multi-linear scheme with a determined yield plateau [13]. The yield stress (f_y) is of 240 N/mm^2 while the ultimate stress (f_u) is of 360 N/mm^2. Material of high strength bolts is modelled as proposed in [4] with yield stress (f_{yb}) of 640 N/mm^2 and ultimate stress (f_{ub}) of 800 N/mm^2. Figures 2 and 3 shows the idealized stress strain curve for both the CHS, end plates and the high strength bolts, respectively. Young's modulus of steel parts (E) is considered as 200 GPa and Poisson's ratio (υ) is taken equal to 0.3.

Four-point loading technique over a hinged-roller beam is adopted to produce pure bending moment on the studied splice. Figure 4 shows that the FE model consists of two CHS parts connected using the configuration of bolts and end plate thickness of the studied splice. Each part has a length of 1100 mm so that the total length of CHS is 2200 mm.

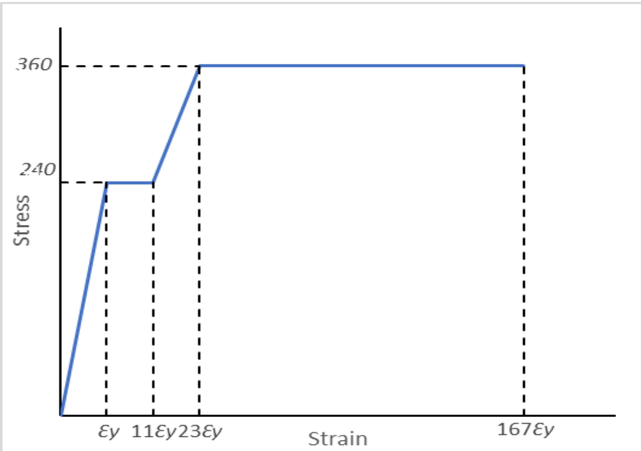

Fig. 2. Stress-strain curve for CHS and end plates (S235JR)

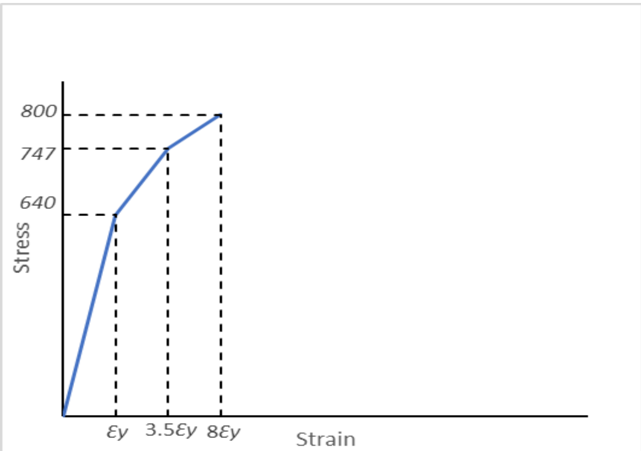

Fig. 3. Stress-strain curve for high strength bolts (A325M)

It has two 200 mm wide bearing plates welded to it at opposite sides of the CHS and spaced 500 mm from each other. The first bearing plate is facing downwards and the hinged or roller boundary condition is applied at its center line so that the theoretical span of the model is 2000mm.

Loading is applied as uniform vertical load at the loading plates as shown in Figure 4 in both quarter points of the span. Boundary conditions is applied as a line support at the center of the base plate that restrain the movement in U_x,U_y and U_z at the hinged end while restraining only U_x and U_y at the roller end, respectively.

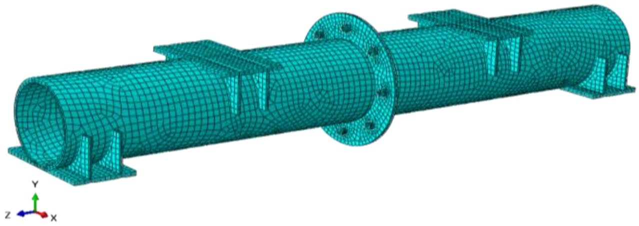

Fig. 4. Finite element model

C. Ultimate moment and general behavior of the CHS solid splice

Ultimate moments obtained from the finite element analysis for all models are tabulated in Table1.

Table I : Finite Element Results

	Plate Thickness (t_{pl})	M_{uFEA} (kN.m)
8M-12	6	85.18
	8	102
	10	112
	12	91.32
	16	91.94
	20	101.9
	24	102.83
	32	107.28
	40	111.77
8M-16	6	79.64
	8	93.91
	10	112.88
	12	125.27
	16	117.92
	20	126.23
	24	136.65
	32	143.21
	40	150.96
8M-20	6	105.15
	8	126.2
	10	139.19
	12	166.63
	16	191.58
	20	180.83
	24	198.83
	32	222.65
	40	232.18

The ultimate moment of the splice is plotted against plate thicknesses in Figure 5 for models with M-12 , M-16 and M-20, respectively.

The figure show that the end plate thickness has substantial effect on the capacity of the connection for the same bolts configuration. These relations show that increasing the end plate thickness for the same

bolts configuration has two distinctive behaviors separated by at a transition thickness.

The relation starts with linear increase in splice ultimate capacity with thickness increase till reaching a transition thickness at which a drop in capacity occurs. After first drop the splice capacity increases with thickness increase but with less gradual slope.

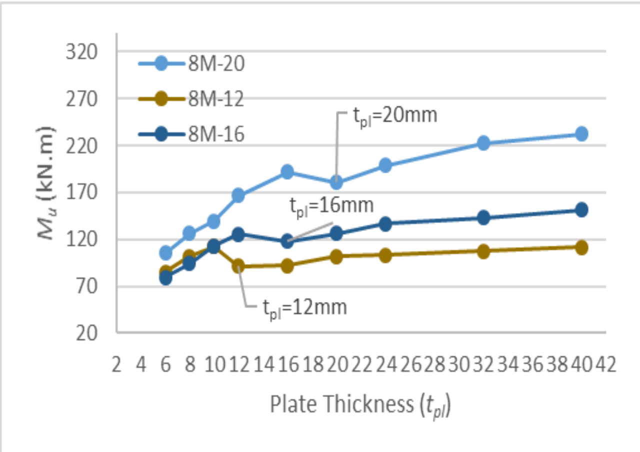

Fig. 5. Ultimate moment vs end plate thickness

Figure 5 shows strength curves for splices. For splices with M-12 bolts, thin or intermediate plate behaviors occurs at thicknesses between 6 to 10 mm end plate thickness. Increasing that thickness from 6 mm to 10 mm increases the ultimate capacity from 85.18 kN.m to 112 kN.m with 31.4% gain in capacity. With reaching the thickness of 12 mm the ultimate capacity drops to 91.32 kN.m. Thick plate behavior occurs between thicknesses of 12 mm and 40 mm, increasing the plate thickness from 12 mm to 40 mm results in increasing the ultimate capacity and reaching a value of 111 kN.m. End plate thickness of 12 mm is considered the transition thickness between the thin or intermediate and thick behaviors for the M-12 models.

The same figure shows that, for M-16 and M-20 models, the same trend occurs. However, the transition thickness for M-16 and M-20 models are 16 mm and 20 mm, respectively. Gain in capacity results from increasing the end plate thickness from 6 mm to the thickness just before the transition thickness becomes more significant by increasing the diameter of bolt. M-16 models gained 57% in ultimate capacity by increasing the end plate thickness from 6 mm to 12 mm. Increasing end plate thickness from 6 mm to 16 mm for M-20 models gains 82% in ultimate capacity.

Failure mode in before transition thickness is governed by the complete yielding of the end plate (Thin plate behavior) or by bolt failure accompanied by excessive end plate deformations (Intermediate plate behavior). After the transition thickness, the governing failure mode is the bolts group failure where extreme bolt reaches its ultimate stress (Thick plate behavior). At the transition stage, the splice behavior is similar to the intermedite plate behavior but with less end plate deformations. To investigate the drop in capacity at the transition thickness, Figures 6 and 7 shows moment versus bolts forces relations for end plates with thicknesses of 10 mm and 12 mm, respectively. It is shown that bolts 1 and 2, for both thicknesses, have reached their ultimate stress. For the case of bolt 3 in 12 mm plate thickness, it did not reach its yield stress (Thick plate behavior), whereas with 10 mm plate thickness it sustains higher stress above the yielding stress till reaching failure of connection (Intermediate plate behavior). This increase in capacity results from the lower stiffness of the 10 mm end plate. It provides the connection with sufficient deformation to sustain higher stress in bolt 3 after yielding of bolts 1 and 2.

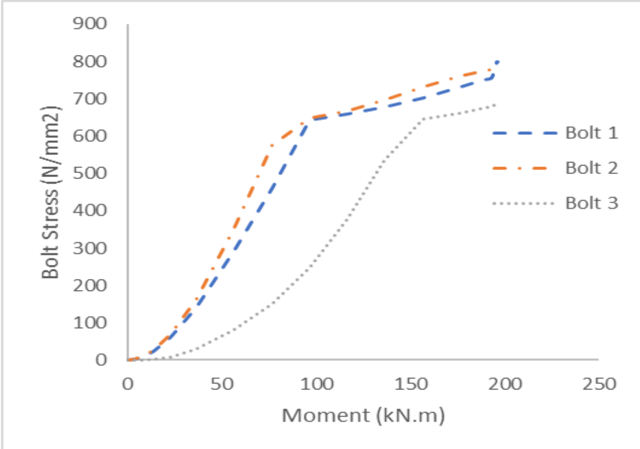

Fig. 6. Bolt stress vs moment for end plate thickness of 10mm

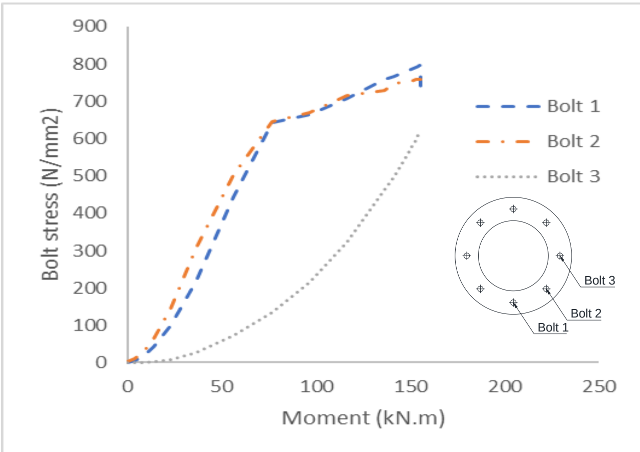

Fig. 7. Bolt stress vs moment for end plate thickness of 12mm

D. Effect of End plate Thickness of the stiffness of the connection

End plate separation is a manifestation for the rotation and deformations of end plate connection with relation to the applied moment. In Figure 8, the moment versus the end plate separation curves for 8M-12 bolts with different end plate thicknesses are shown. For thicknesses of 6, 8 and 10 mm, the end plate exhibits relatively excessive deformations where the connecting plate has lower stiffness value. For thicknesses from 16 mm to 40 mm, the stiffness and the moment-plate separation curves are almost identical with relatively high stiffness and small deformations.

End plate thickness of 12 mm is considered as the transition stage
between the intermediate plate behavior and thick plate behavior.Although end plate thickness of 10 mm has a higher ultimate moment than the 12 mm thickness. However, the lower stiffness of the 10 mm may not be accepted from the serviceability point of view.Figures 9 and 10, respectively, show the moment versus the end plate separation curves for 8M-16 and 8M-20 bolts versus all plate thicknesses considered. For M-16 connections, the end plate thicknesses from 6 mm to 12 mm show thin plate behavior. For thicknesses from 20 mm to 40 mm, thick plate behavior occurs.
End plate thickness of 16 mm is considered the transition stage. For M-20 connections, end plate thickness of 20 mm is considered the transition thickness between the two different behaviors.

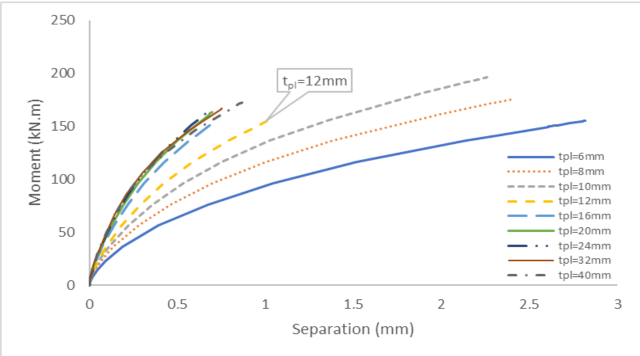

Fig. 8. Moment-separation relation for 8M-12 bolts splices

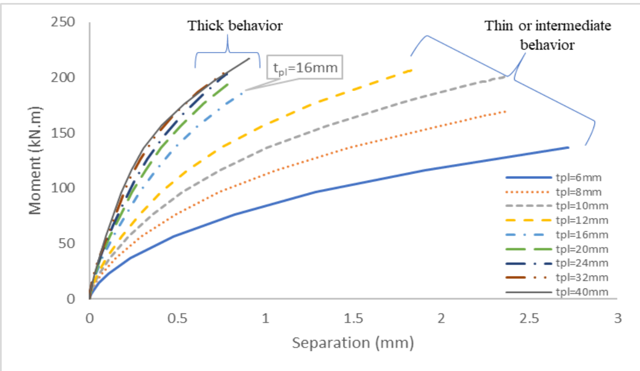

Fig. 9. Moment-separation relation for 8M-16 bolts splices

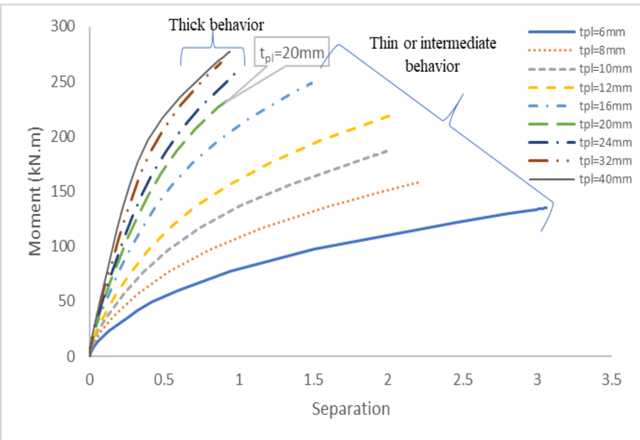

Fig. 10. Moment-separation relation for 8M-20 bolts splices

III. SUMMARY AND CONCLUSIONS

1. A Finite element study is carried out to investigate the behavior of CHS splice connection. Finite element model is verified against experimental results conducted for this subject study. The study includes different geometrical configurations covering bolt sizes, end plate thicknesses.
2. Increasing connection end plate thickness results in increasing the capacity of the connection up to a certain limit “Transition thickness” where the capacity decreases then starts to linearly increase again but with less slope.
3. The connection acts as thin or intermediate behavior up to the drop thickness then after this thickness behavior transforms into the thick behavior accompanied by drop in capacity.
4. Connection stiffness is greatly affected by the end plate thickness. Lower end plate thickness may have a higher ultimate moment. However, it may not be accepted from the serviceability point of view.

REFERENCES

1. E. Sumner, Unified Design of Extended End-Plate Moment Connections Subject to Cyclic Loading, (Ph.D Thesis) Virgnia Polytechnic Institue and State University, USA, 2003.
2. M.R. Bahaari, A.N. Sherbourne, 3D Simulation of Bolted Connections to Unstiffened Columns - II. Extended Endplate Connections, J. Constr. Steel Res. 40 (1996) 189–223.
3. A.N. Sherbourne, M.R. Bahaari, 3D Simulation of Bolted Connections to Unstiffened Columns - I. T-stub Connections, J. Constr. Steel Res. 40 (1996) 169–187.
4. A.K. Dessouki, A.H. Youssef, M.M. Ibrahim, Behavior of I-beam Bolted Extended End-Plate Moment C onnections, Ain Shams Eng. J. 4 (2013) 685–699. doi:10.1016/j.asej.2013.03.004.
5. N. Krishnamurthy, D.E. Graddy, Correlation Between 2- and 3-Dimensional Finite Element Analysis of Steel Bolted End-Plate Connections, Comput. Struct. 6 (1976) 381–389.
6. B. Kato, A. Mukai, Bolted Tension Flanges Joining Square Hollow Section Members, J. Constr. Steel Res. 5 (1985) 163–177. doi:10.1016/0143-974X(85)90001-X.
7. B.A.T. Wheeler, M.J. Clarke, G.J. Hancock, Tests of Bolted Moment End Plate Connections in Tubular Members, in: Proc. 14th Aust. Conf. Mech. Struct. Mater., University of Tasmania, Hobart - Tasmania - Australia, 1995: pp. 331–336.
8. B.A.T. Wheeler, M.J. Clarke, G.J. Hancock, Design Model for Bolted Moment End Plate Connections using Rectangular Hollow Sections, Sydney, 1997.
9. B.A.T. Wheeler, M.J. Clarke, G.J. Hancock, FE Modeling of Four-Bolt , Tubular Moment End-Plate Connections, J. Struct. Eng. (2000) 816–822.
10. Y.Q. Wang, L. Zong, Y.J. Shi, Bending Behavior and Design Model of Bolted Flange-Plate Connection, J. Constr. Steel Res. 84 (2013) 1–16. doi:10.1016/j.jcsr.2013.01.012.
11. F.E.A. Software, Simulia - ABAQUS v6.14-5, (2016).
12. A. M.Ibrahim, T. H.Radwan, S. A.Ibrahim, A. K.Dessouki, Experimental Investigation of Circular Hollow Sections Flanged Splice, Submitt. Publ. (n.d.).
13. A.J. Sadowski, J. Michael Rotter, P.J. Stafford, T. Reinke, T. Ummenhofer, On The Gradient of The Yield Plateau in Structural Carbon Steels, J. Constr. Steel Res. 130 (2017) 120–130. doi:10.1016/j.jcsr.2016.11.024.

ISSN: 2277-3878 (Online), Volume-8 Issue-6, March 2020

AUTHORS PROFILE

Ahmed M.Ibrahim : PhD candidate , Assistant Lecturer - Structural Engineering Department - Ain Shams University. **Education:** MSc. in Structural Engineering, Faculty of Engineering, Ain Shams University.
Research Interests: Cold-formed section, Design and behavior of steel structures.

Tamer H.Radwan : Assistant Professor - Structural Engineering Department - Ain Shams University. **Education:** Ph.D. in Structural Engineering, Faculty of Engineering, Ain Shams University.

Research Interests: Steel Structures, Steel Connection, Fatigue performance of metals.

Sherif A.Ibrahim : Professor of Steel Structures and Bridges - Structural Engineering Department - Ain Shams University. **Education:** Ph.D. in Structural Engineering, Drexel University, USA, Oct 2001. **Research Interests:** Steel design, Plate girder, Corrugated web, Fatigue performance of metals.

Abdelrahim K.Dessouki : Professor of Steel Structures and Bridges - Structural Engineering Department - Ain Shams University. **Education:** Ph.D. Civil Engineering Department, University of Windsor, Canada, Jan. 1985.
Research Interests: Design and behavior of steel structures, Cold-formed steel design and behavior, Fatigue performance of metals.