Indian Journal of Science and Technology, *Vol 10(8), DOI: 10.17485/ijst/2017/v10i8/111225, February 2017*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Finite Element Analysis of Beam to Column Bolted Connection – A Review

K. Al Fakih[1], S. C. Chin[1,2]* and S. I. Doh[1,3]

[1]Department of Civil Engineering and Earth Resources, Universiti Malaysia Pahang, 26300 Gambang, Pahang, Malaysia;
[2]Department of Excellence for Advanced Research in Fluid Flow (CARIFF), Universiti Malaysia Pahang, 26300 Gambang, Pahang, Malaysia; scchin@ump.edu.my
[3]Department for Earth Resources Research and Management (CERMM), Universiti Malaysia Pahang, 26300 Gambang, Pahang, Malaysia;

Abstract

Objectives: This paper contains the review of studies performed on the behavior of steel beam-to-column connections by using finite element analysis computer package known as "Abaqus, Ansys, etc" from the theoretical and practical points of view. The objective of this article is providing the foundation for the design and analysis faster and more economical and securing the required strength for the connection steel. **Methods/Statistical Analysis:** Nearly seventy-one academic and popular research/literature in the field of steel connections had been studied in which an overview of recent events has made the construction of the system viable in the infrastructure. **Findings:** Linear analysis of connection behavior is very complicated since there is no immediate solution for it. All the results of the accounts of the design connections cannot be verified only through lab tests which consume a lot of time, money and effort. Therefore, the availability of simulation programs can overcome these problems. This article will be of value to anyone seeking better understanding in the area of steel beam-to-column connections behavior. **Application/Improvements:** Review study presented in this paper can be used as reference for future investigation especially in the member strength and development of the design approach for steel beam-to-column connections with simulation models.

Keywords: Angles, Abaqus, Ansys, Bolted Connection, Finite Element Method (FEM), Steel Beam

1. Introduction

In a multi-story beam to column connection, various ways have been found to estimate the failure of connection between the steel beams to columns. There are many different types of connections, namely the double-web angles, top and seat angles, top and seat &double-web angles as well as extended end-plate connections[1]. All of these connections are bolted-bolted, bolted-welded or welded-welded connections. The steel connections have shown a high nonlinear behavior due to the plasticity of the material and the slenderness of the members. Therefore, knowing how to handle the "real" behavior of steel-to-column, beam connections have been a major topic in the field of steel structure design calculation research.

Steel connections are classified into two types; fully restrained and partially restrained. According to the American Steel Construction Institute (AISC), it is expected that fully restrained connections have enough stiffness to sustain angles between the intersecting members, commonly referred as simple framing; the connections have sufficient inelastic rotation capacity. The connection behaviour between beam and column in structural steel frames may be adequately represented by the behavioral forces that are evident from the momentum rotation ratio in the first place. Even at low load levels, the behavior of this connection is identified as non-linear

*Author for correspondence

characterized by the moment-rotation curves. In addition, the moment-rotation curves demonstrate a complex interaction between the elementary sections establishing the joint. This work reviewed the various techniques used to study the joint failure of a bolted connection in the steel structures, such as steel buildings, bridges, hangars and so on.

2. Materials and Methods

The methodology of this study comprises of two parts; (i) Traditional method, (ii) Finite Element (FE) method using software. The first part deals with the trends prevailing in the numerical method while the second part discusses on the modeling techniques. The review conducted includes research papers published in the period of 1990–2015. Hence, this would provide a concise summary of the work done in the field of beam-to-column bolted connections in the steelwork structures using traditional method or Finite Element Analysis (FEA).

2.1 Traditional Method

The important elements of steel frame are beam-to-column connections and their behavior which affects their performance under various loadings. When designing steel structures, joints are usually assumed either pinned or totally rigid. However, the connections act in-between the two extreme assumptions and has some rotation rigidity instead; and this has been confirmed by many researchers.

Past decades revealed that the growth of methods to analyze the not fully rigid joint connections adopted from the slope-deflection equations for stability[2] which then utilize a power relationship between the model rotation and the end moment in the connection[3]. Connection parameters for frame angle connections, and connections with various angles were eventually developed and generalized[4,5] to the matrix stiffness methods[6,7] and currently, the method of global structural analysis of iterative coupling with joint analysis[8-11]. It is also reported that joint rotation behavior should be considered in the frame analysis[8,9,12]. The applications for all these studies are performed by referring to the curve of the moment and rotation. Numerical modeling by FEA is conducted to determine the joints mechanical performance. Today, researchers and manufacturing companies started to use Finite Element Method (FEM), for several reasons:

i. Alternative to complex experimental methods.
ii. Acquisition time, effort and money.
iii. To find important local effects that unable to measure experimentally.
iv. To find wide parametric studies.
v. To determine the Moment Rotation-Curves and rotational behavior of a joint.

Several studies of beam-column connections have been conducted which can be used are: empirical[13], analytical[2,14], experimental[15-17] informational[18,19] and mechanics[19-21]. Three types of common connections in steel frame systems are used, including all welded, all bolted, and welded-bolted connections. Under all welded connections, the beam is welded to the column, whereas in all-bolted connections, the beam is bolted to the column. On the other hand, in welded-bolted some components of the connection are welded whilst others are bolted to the column and beam flanges. The connections are categorized into three types: rigid, pinned, and partially restrained or semi-rigid. In a rigid connection, the moment is fully transferred from the beam to the column. These connections possess limited ductility which makes them prone to fracture failure. Meanwhile, in pinned connections, no relocation of moment of the beam to the column was traced and the connections are assumed to be completely free to rotate. A portion of the moment of the beam is transferred to the column in a partially restrained or semi-rigid connection. Partial rotation of the connection is allowed to occur in these connections. Hence, the Partially Restrained Connections (PRC's) possess high flexibility and high energy dissipating capabilities which make them perfectly suitable for regions prone to seismic activity. The followings are the commonly adopted PRC's:

i. Seat and top angles connections (TSA).
ii. Connections of double web angle (DWA)
iii. Connection of Top and Seat Angles with Double Web Angles (TSA -DWA).
iv. End-Plate connections (EP).

Description of the behavior of a connection for a moment rotation curve is depicted shown in Figure 1.

An experimental work was conducted on ten beam-to-wide flange-column (bolted-web, welded-flange) connections[22]. The key parameters in this study, including

flange-beam to the whole supplemental web bolts, beam section plastic modulus ratio and column – panel zone strength and supplemental web welds. In another study, a detailed failure analysis of nearly 20 fractures of buildings damaged during the Northridge earthquake was reported[23]. On the other hand, different kinds (welded and bolted) of column-to-beam connections was studied experimentally. The experimental work covers six tests which include (three welded and three bolted) different groups of specimens with a total of thirty-six tests[24]. The purpose of this test program was to have the same representation of the similar behavior of welded and bolted joints, as well as to study the influence of the size of the column and the design of the panel zone on the behavior of the two forms of connections. Meanwhile, researchers[25] presented two types of half rigid double-web angle joints: bolted ends and welded-bolted, in which the bolts were pretension to the proof load. The test was conducted on twenty samples subjected to cyclic loading. The samples were loaded separately controlled by the load at the early stage of each cycle. Hysteresis loops of the moment rotation as well as the types of failure for every test were reported. The connection values of the ultimate moment capacity, initial stiffness, failure modes and ultimate rotation capacity were also presented[24]. The behavior of

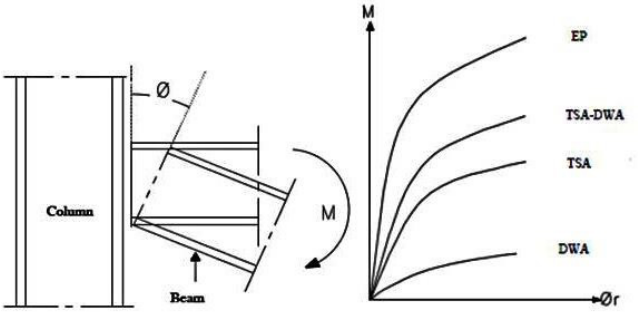

Figure 1. Typical moment rotation (M-Ø) curve of beam-to-column connections.

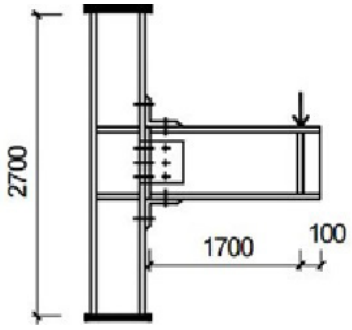

Figure 2. Typical top-seat and web angles connection.

semi-rigid connections was also investigated[26]. Three full-scale specimens of steel angles had been conducted as shown in Figure 2.

The specimens were subjected to dynamic inversion loading simulating earthquake cause on a steel moment-resisting force. The main objective of this study[26] was to identify the behavior of these connections under cyclic reverse loading in the form of plastic range as well as to ascertain the effects of design parameters. On the other hand, the performance of the blind-bolted angle joints between tubular columns and open beams were also studied[26]. Several methods of contact with the characteristics of the bolts of different geometric arrangements were analyzed. A total of seventeen monotonous and cyclic connections with top and seat angle connections, as well as web-angles connections were tested. Findings reported that the extension is caused by the interior of the blind bolts. Furthermore, deformations in bending on the face of the column must be limited in design in order to fulfill the service ability requirements. Simplified analytical method together with the experimental results demonstrates the adequate use of partial / half rigid joint for the secondary systems or basic frame, which depends on the particular structural arrangement and the load conditions.

As the building industry are developing, the analysis methods of moment distribution methods are evolving; from semi-rigid connection, to various equations and iterative methods combining the global and joint structural analyses. Results of the findings come to an agreement that in the analysis of frames, the joint rotation behavior should be taken into account. This is normally performed by adopting the curve of the moment and rotation. Various models, i.e. empirical, analytical, experimental, mechanical and numerical can be used to determine joint mechanical behavior as well, with detailed studies reported in the literature[3,9,10,27-35]. On the other hand, researchers also collected the steel connection M–θ data from more than 300 tests result[3,36]. Several models of M-θ, which is the model of Three Parameters of Power, acquired the most attention.

2.2 FEMs using Software

There are many software programs which can be used to analyze and study the joint behavior using FEM such

as ANSYS and ABAQUS. Many researchers used these programs in their research, especially those that are difficult to get accurate results[37,38]. A model was developed to study the conduct of the connections of bolted steel of the extended end-plate[39], contacts T-stub[40] and the end of the connection of a long insulated plate[39,34]. Response characteristics and failure modes were accurately captured by non-linear FE models[41,42]. While numerous studies have been done on steel moment-connections subjected to cyclic loading, relatively few publications have been reported on moment connections subjected to short impulse loading. Most studies focus on blast loading of frame structures, not the individual joints. However, numerical studies conducted[43] revealed that the FEM can be used to assess the stress distribution in moment connections under blast loading[43]. In addition to experimental investigations, a few of the experiments were accompanied by finite element analyses to further understand the performance of beam connections to column[44-49] studied the impact of angle thickness and bolt gage space at the relationship between moment and rotation for the joints of double-web angle and the stress distribution of every sample. Plastic – elastic constitutive law is assumed to the samples that are exposed to shear loads.

Similarly, the nonlinear behavior of steel connection for a double-web angle can be simulated using simulation programs. Laboratory testing under similar geometrical and material state were observed to ensure that FEA of the test results was verified by comparing the curves of rotational element momentum and deformation aspects derived from the analysis and tests. The closer the gage space and thicker angle can produce a higher initial stiffness. Mean while, a three dimensional FE on the conduct of the moment-rotation curve for the seat and top angle links with the double-web angle joints; notably the early stiffness of this type of connections is subjected to both moment and shear force were studied[50]. All the contact elements in these models such as angles, bolts, beams, and columns are modeled using brick elements of eight nodes. The consequences of falling element interactions, such as frictional forces and slippage of bolts are modeled by surface contact algorithm. In order to simulate the behavior of a contact more accurately, pre-tensioning of the bolt is assigned on the bolt shanks as the first load case. The results of the analysis obtained in this study were compared with the available results of experimental data from the literature and showed good agreement[50], as shown in Figure3.

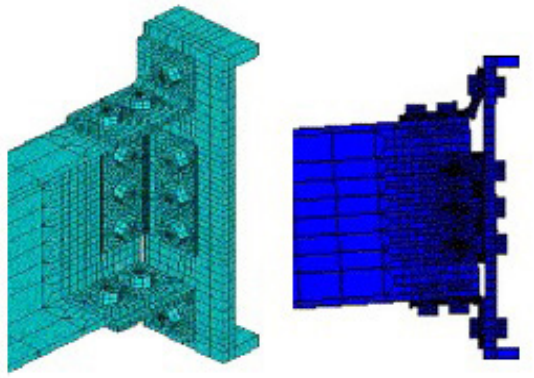

Figure 3. Deformed shape of connection.

The performance of top bolted and seat angle joints; the moment of the new rotation was investigated. Partial analytical equations adopted in this study are according to the database that was created by FE simulation[51]. Many refined three-dimensional FE models were developed based on the test results and validated by comparing to the other numerical models that have been published with the results adopted from past investigations. Meanwhile, the effect of half-rigid joint properties on the steel structure connection's performance was studied, and eventually created a three-dimensional FE model to study the performance of moment - rotation of the connections with an eight-bolt stiffened end-plate[52]. Further investigations to quantify the performance of the seat-top angle bolted connection with web angles connections by various three-dimensional models[53] as well as to simulate the performance of end-plate bolted connections by using an eight-node sub-parametric bricks in the analysis[54].

Taking into account the weakening of steel properties due to high temperature and the importance of the effect of contact behavior on steel structures, it is crucial to understand the behavior of certain steel joints subjected to fire as well as the knowledge on the impact of fire on the main constituent properties of steel connections. Steel structures and connection joints between them may be exposed to direct heat or transferred from the source of fire from nearby heating. The collision of a flame from the localized fire may lead to higher temperatures in all the members of the exposed steel structure, which will lead to a change of properties and steel specifications and that can cause structural failure. Hence, overwhelming interest has been received by researchers to study the impact of fire on the steel beam to column connections, the provision of rotational moment properties and related param-

eters of the half rigid beam to column connection as well as to identify the moment-rotation curve (M-Ø) under high temperature. A study was conducted to model the bolted end-plate connection at increased temperatures using 2-noded connection element. The contact element allows for the nodes of the elements at the locations and levels can transfer distributions temperatures and loads; are not uniform in the connection elements of the steel structure. Considered in this model, the connection failure included compression, bending, axial tension, and vertical shear. The effect of the axial tensile force of the connected beam is also considered in this study. A total of 23 fire tests were performed to verify the large-scale model. It was found that the current model is robust and has the ability to forecast the behavior of a bolted end-plate connection being attacked under fire with realistic accuracy[55]. Another numerical study of 10 simulated fire test was conducted on restraint beam-column steel connection by five types of different joints: the end of a flex plate, fin plate, web cleat, extended end-plate and flush end-plate. The analysis performed was linearly elastic but costly since the contact was artificially embodied by nodes in the form of attached and released at every loading step on the basis of stress distribution,[56] as illustrated shown in Figure 4.

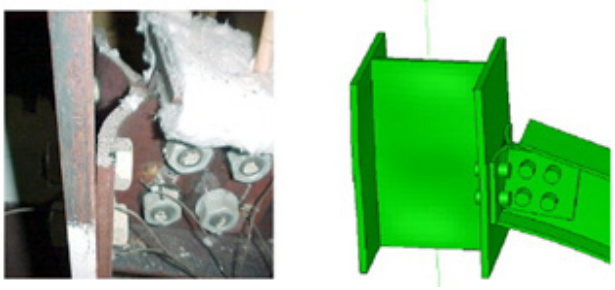

Figure 4. Comparison of simulation and observed deformation patterns of web connection.

Mean while, a qualitative study of the importance of gravity columns on the stability behavior of a steel building with typical lengths consisting of ten-storey, is subjected to fire at the corner compartments[56]. The effect of the gravity loads and the impact of shock, fire on this building were predicted using numerical analysis and FE study. From the numerical investigation, results showed that under the condition of the fire, the gravity columns can control the entire construction stability. To ensure overall structural stability in the case of failed column, the load taken by the failed gravity column has to be redistributed to the neighboring columns. Results of FEA revealed that the presence of reinforcing bars in the concrete slabs with the minimum shrinkage reinforcement was able to uniformly distribute the axial load encountered by the failed gravity column to the neighboring columns[55]. On the other hand, a numerical study was conducted by ABAQUS to simulate the end-plate connections of high strength steel under fire conditions in order to study the behavior of the joints subjected to fire. A good agreement was obtained through validation of experimental and numerical results which include the curve of moment-rotation, yield line trend of the connections as well as the failure behavior. Hence, this signifies that FEA can provide accurate results compared to experimental results[57].

Numerous published researches focused on steel beam and column connections behavior using analysis of FEA under the influence of load and different boundary conditions, some of which have been studied under the effect of degradation properties due to high temperatures of the fire. Furthermore, coupled with the high-temperature effects on the residual strength of steel beam connection to column shear-moment connections were studied. The findings of the analysis obtained in this study were compared with the available results of experimental data from the literature[58,59]. Meanwhile, the effect of high temperatures on the behavior of welded angle joints using the FE program, ABAQUS was also studied as shown in Figure 5.

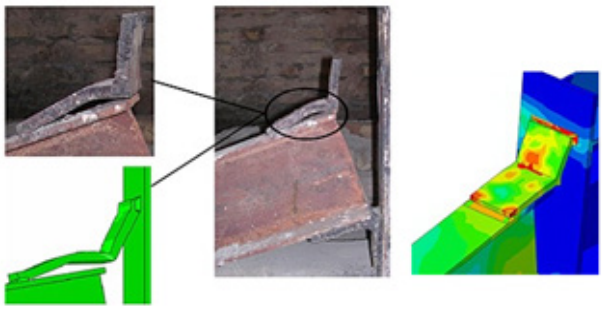

Figure 5. Comparison of the simulation with the welded angle connection.

The mechanical and thermal conducts of the restrained steel beams subjected to fire, flame shocks were numerically investigated. In this case, four different dimensions of steel beam and restraints were considered. The variables involved developing and constant burning fires. For comparison purposes, ISO834 standard for fire was adopted. From the results obtained, it was found that

the temperature distributions inside the steel beams due to collision of flame are greatly non-uniform throughout the beams. It was reported that along the length of the beam, the temperature near the fire source may be greater than those away. In addition, different temperature distributions may affect the deformation mode for the restraint steel beam. Compared to the restraint steel beams under standard fire, the failure temperatures due to localized fire may be higher and lower[60].

Taking into account the deterioration of steel properties under various loads as well as the importance of steel connection behavior, it is important to understand the behavior of a specific steel connection subjected to loading and fire which is necessary for a safe design. For this reason, there are many researchers who are interested in studying the steel beam-to-column connection behavior. This review was performed based on the published researches[61-70].

3. Conclusion

This review summarizes the previous researches published in the area of steel beams connections in the traditional method and FEM using software in the field of bolted connections. Bolted connection is a common design in steel beam connections; however, extra considerations should be taken when designing bolted steel beam connections in accordance with the Eurocode. There are some gaps of knowledge that are needed to be filled with the design codes for the steel beam connections. This could be completed with comprehensive future research with steel beam to column connections under different types of load behavior and high temperature. The innovative design of joints for a steel beam connections system and improvable technology for steel beam structures are also worth to be reviewed and compiled for advancing knowledge. The International Conference on Fluids and Chemical Engineering (FluidsChE 2017) is the second in series with complete information on the official website[72] and organized by The Center of Excellence for Advanced Research in Fluid Flow (CARIFF)[73]. The publications on chemical engineering allied fields have been published as a special note in volume 3[74] Host being University Malaysia Pahang[74] is the parent governing body for this conference.

4. Acknowledgement

We have tried to focus on the helpful references in this document, and we apologize for the inadvertent incomplete references and would welcome ideas and suggestions of other related literature to further improve on this topic. The authors also wish to acknowledge the support from the Universiti Malaysia Pahang (UMP) and the Ministry of Higher Education of Yemen for this research work.

5 References

1. Agarwal A, Varma AH. Fire induced progressive collapse of steel building structures: The role of interior gravity columns. Engineering Structures. 2014 Jan; 58:129–40. Crossref
2. Aristizabal-Ochoa JD. Slope-deflection equations for stability and second-order analysis of Timoshenho beam–column structures with semi-rigid connections. Engineering Structures. 2008 Sep; 30(9):2517–27. Crossref
3. Kishi N, Chen W-F. Moment-rotation relations of semirigid connections with angles. Journal of Structural Engineering. 1990 Jul; 116(7):1813–34. Crossref
4. Liew JR, White D, Chen W. Limit states design of semi-rigid frames using advanced analysis, part 1, connection modeling and classification. Journal of Constructional Steel Research. 1993; 26(1):1–27. Crossref
5. Liew JR, White D, Chen W. Limit states design of semi-rigid frames using advanced analysis: Part 2: analysis and design. Journal of Constructional Steel Research. 1993; 26(1):29–57. Crossref
6. Kanchi MB. Matrix methods of structural analysis. New Age International; 1993. p. 561.
7. Livesley RK. Matrix methods of structural analysis: pergamon international library of science, technology, engineering and social studies. 2nd edtion. Elsevier; 1975 Jan 1. p. 290.
8. Almusallam T, Richard R. Steel frame analysis with flexible joints exhibiting a strain-softening behavior. Computers and Structures. 1993 Jan 3; 46(1):55–65. Crossref
9. Jaspart J-P, Maquoi R. Guidelines for the design of braced frames with semi-rigid connections. Journal of Constructional Steel Research. 1990; 16(4):319–28. Crossref
10. Cabrero J, Bayo E. Development of practical design methods for steel structures with semi-rigid connections. Engineering Structures. 2005 Jul; 27(8):1125–37. Crossref
11. Aristizabal-Ochoa JD. Second-order slope–deflection equations for imperfect beam–column structures with semi-rigid connections. Engineering Structures. 2010 Aug; 32(8):2440–54. Crossref
12. Faella C, Piluso V, Rizzano G. Structural steel semirigid connections: theory, design, and software. CRC press; 1999.
13. Frye MJ, Morris GA. Analysis of flexibly connected steel frames. Canadian Journal of Civil Engineering. 1975 Sep; 2(3):280–91. Crossref

14. Yee YL, Melchers RE. Moment-rotation curves for bolted connections. Journal of Structural Engineering. 1986 Mar; 112(3):615–35. Crossref
15. Bryan E, Sedlacek G, Tomà A, Weynand K. Evaluation of test results on connections in thin walled sheeting and members in order to obtain strength functions and suitable model factors. Background Document A; 1990. p. 1.
16. Bjorhovde R et al. Connections in steel structures II: behavior, strength, and design: proceedings of the second international workshop held at westin william penn hotel, Pittsburgh, Pennsylvania, USA, april 10–12, 1991. American Institute of Steel Construction; 1992. p. 464.
17. Kim J, Ghaboussi J, Elnashai AS. Mechanical and informational modeling of steel beam-to-column connections. Engineering Structures. 2010 Feb; 32(2):449–58. Crossref
18. Cevik A. Genetic programming based formulation of rotation capacity of wide flange beams. Journal of Constructional Steel Research. 2007 Jul; 63(7):884–93. Crossref
19. da Silva LS, Coelho AG. An analytical evaluation of the response of steel joints under bending and axial force. Computers and Structures. 2001 Mar; 79(8):873–81. Crossref
20. Lemonis ME, Gantes CJ. Mechanical modeling of the nonlinear response of beam-to-column joints. Journal of Constructional Steel Research. 2009 Apr; 65(4):879–90. Crossref
21. European Committee for Standardization. Eurocode 8: Design of structures for earthquake resistance – Part 2: Bridges. The European Union; 2005. p. 6–147.
22. Popov EP, Tsai K. Performance of large seismic steel moment connections under cyclic loads. Engineering Journal. 1989; 26(2):51–60.
23. Kaufmann EJ, Xue M, Lu L-W. Achieving ductile behavior of moment connections – Part II. Modern Steel Construction. 1996 Jun; 36(6): 38–42.
24. Calado L, Mele E editors. Experimental behavior of steel beam-to-column joints: fully welded vs. bolted connections. In the Proceedings of the 12th World Conference on Earthquake Engineering. 2000; 2570:1–8.
25. Elghazouli A, Málaga-Chuquitaype C, Castro J, Orton A. Experimental monotonic and cyclic behaviour of blind-bolted angle connections. Engineering Structures. 2009 Nov; 31(11):2540–53. Crossref
26. Xinwu W editor. Experimental research on hysteretic behavior of top-seat and web angles connections. 5th WSEAS International Conference on Environment, Ecosystems and Development, Tenerife, Spain. 2007 Dec 14–16. p. 75–9.
27. Chen W-F. Practical analysis for semi-rigid frame design. World Scientific; 2000 Jul. p. 480. Crossref
28. Vellasco PCGdaS, de Andrade SAL, da Silva JGS, de Lima LRO, Jr OB. A parametric analysis of steel and composite portal frames with semi-rigid connections. Engineering structures. 2006 Mar; 28(4):543–56. Crossref
29. Bayo E, Cabrero J, Gil B. An effective component-based method to model semi-rigid connections for the global analysis of steel and composite structures. Engineering Structures. 2006 Jan; 28(1):97–108. Crossref
30. Yang J, Lee G. Analytical model for the preliminary design of a single-storey multi-bay steel frame under horizontal and vertical loads. Journal of Constructional Steel Research. 2007 Aug; 63(8):1091–101. Crossref
31. Daniūnas A, Urbonas K. Analysis of the steel frames with the semi-rigid beam-to-beam and beam-to-column knee joints under bending and axial forces. Engineering structures. 2008 Nov; 30(11):3114–8. Crossref
32. Ihaddoudene A, Saidani M, Chemrouk M. Mechanical model for the analysis of steel frames with semi rigid joints. Journal of constructional Steel research. 2009 Mar; 65(3):631–40. Crossref
33. Ali NBH, Sellami M, Cutting-Decelle A-F, Mangin J-C. Multi-stage production cost optimization of semi-rigid steel frames using genetic algorithms. Engineering Structures. 2009 Nov; 31(11):2766–78. Crossref
34. Nethercot D, Zandonini R. Structural connections: stability and strength: chapter 2: methods of prediction of joint behaviour: beam-to-column connections. Jason Consultants SA; 1989. p. 23–62.
35. Abdalla KM, Chen W-F. Expanded database of semi-rigid steel connections. Computers and Structures. 1995 Aug 17; 56(4):553–64. Crossref
36. Kishi N, Matsuoka K, Chen W-F, Nomachi S. Moment-rotation relation of top-and seat-angle connections. Memoirs of the Muroran Institute of Technology, Science and Engineering. 1987 Nov 10; 37:163–72.
37. Bursi O, Jaspart J-P. Calibration of a finite element model for isolated bolted end-plate steel connections. Journal of Constructional Steel Research. 1997 Dec; 44(3):225–62. Crossref
38. Bursi O, Jaspart J-P. Basic issues in the finite element simulation of extended end plate connections. Computers and Structures. 1998 Nov; 69(3):361–82. Crossref
39. Sherbourne AN, Bahaari MR. 3D simulation of end-plate bolted connections. Journal of Structural Engineering. 1994 Nov; 120(11):3122–36. Crossref
40. Bursi O, Jaspart J-P. Benchmarks for finite element modelling of bolted steel connections. Journal of Constructional Steel Research. 1997 Jul–Sep; 43(1–3):17–42. Crossref
41. Yang B, Tan KH. Numerical analyses of steel beam–column joints subjected to catenary action. Journal of Constructional Steel Research. 2012 Mar; 70:1–11. Crossref
42. Sadek F, Main JA, Lew HS, El-Tawil S. Performance of steel moment connections under a column removal scenario. II: Analysis. Journal of Structural Engineering. 2013 Jan; 139(1):108–19. Crossref

43. Sabuwala T, Linzell D, Krauthammer T. Finite element analysis of steel beam to column connections subjected to blast loads. International Journal of Impact Engineering. 2005 Aug; 31(7):861–76. Crossref
44. Lee C-H, Kim J-H. Seismic design of reduced beam section steel moment connections with bolted web attachment. Journal of Constructional Steel Research. 2007 Apr; 63(4):522–31. Crossref
45. Zekioglu A, Mozaffarian H, Uang C-M editors. Moment frame connection development and testing for the city of hope national medical center. Building to last: proceedings of Structures Congress XV, American Society of Civil Engineers, New York. 1997; 1:100–4.
46. Zhang X, Ricles JM. Experimental evaluation of reduced beam section connections to deep columns. Journal of Structural Engineering. 2006 Mar; 132(3):346–57. Crossref
47. Jones SL. Reduced beam section welded steel moment frames. In the Proceedings of the 12th World Conference on Earthquake Engineering. 2000; 1671:1–8. http://www.iitk.ac.in/nicee/wcee/article/1671.pdf.
48. Gilton CS, Uang C-M. Cyclic response and design recommendations of weak-axis reduced beam section moment connections. Journal of Structural Engineering. 2002 Apr; 128(4):452–63. Crossref
49. Hong K, Yang J, Lee S. Moment–rotation behavior of double angle connections subjected to shear load. Engineering Structures. 2002 Jan; 24(1):125–32. Crossref
50. Danesh F, Pirmoz A, Daryan AS. Effect of shear force on the initial stiffness of top and seat angle connections with double web angles. Journal of Constructional Steel Research. 2007 Sep; 63(9):1208–18. Crossref
51. Pirmoz A, Khoei AS, Mohammadrezapour E, Daryan AS. Moment–rotation behavior of bolted top–seat angle connections. Journal of Constructional Steel Research. 2009 Apr; 65(4):973–84. Crossref
52. Kukreti AR, Zhou F-F. Eight-bolt endplate connection and its influence on frame behavior. Engineering structures. 2006 Sep; 28(11):1483–93. Crossref
53. Pirmoz A, Daryan AS, Mazaheri A, Darbandi HE. Behavior of bolted angle connections subjected to combined shear force and moment. Journal of Constructional Steel Research. 2008 Apr; 64(4):436–46. Crossref
54. Krishnamurthy N, Graddy DE. Correlation between 2-and 3-dimensional finite element analysis of steel bolted end-plate connections. Computers and Structures. 1976 Aug–Oct; 6(4–5):381–9. Crossref
55. Huang Z. A connection element for modelling end-plate connections in fire. Journal of Constructional Steel Research. 2011 May; 67(5):841–53. Crossref
56. Dai X, Wang Y, Bailey C. Numerical modelling of structural fire behaviour of restrained steel beam–column assemblies using typical joint types. Engineering Structures. 2010 Aug; 32(8):2337–51. Crossref
57. Qiang X, Bijlaard FS, Kolstein H, Jiang X. Behaviour of beam-to-column high strength steel endplate connections under fire conditions–Part 1: Experimental study. Engineering Structures. 2014 Apr 1; 64:23–38. Crossref
58. Hean LS, Sulong NHR, Jameel M. Effect of axial restraints on top-seat angle connections at elevated temperatures. KSCE Journal of Civil Engineering. 2015 Dec 30. p.1–9.
59. Yahyai M, Daryan AS. The study of welded semi-rigid connections in fire. The Structural Design of Tall and Special Buildings. 2013 Jul; 22(10):783–801.
60. Zhang C, Li G-Q, Usmani A. Simulating the behavior of restrained steel beams to flame impingement from localized-fires. Journal of Constructional Steel Research. 2013 Apr; 83:156–65. Crossref
61. Ataei A, Bradford MA, Valipour HR. Moment-rotation model for blind-bolted flush end-plate connections in composite frame structures. Journal of Structural Engineering. 2014; 141(9):0401–4211 Crossref
62. Coelho AMG. Rotation capacity of partial strength steel joints with three-dimensional finite element approach. Computers and Structures. 2013 Jan 15; 116:88–97. Crossref
63. Díaz C, Victoria M, Martí P, Querin OM. FE model of beam-to-column extended end-plate joints. Journal of Constructional Steel Research. 2011 Oct; 67(10):1578–90. Crossref
64. Drosopoulos G, Stavroulakis G, Abdalla K. 3 D Finite element analysis of end- plate steel joints. Steel and Composite Structures. 2012; 12(2):93–115. Crossref
65. Gerami M, Saberi H, Saberi V, Daryan AS. Cyclic behavior of bolted connections with different arrangement of bolts. Journal of Constructional Steel Research. 2011 Apr; 67(4):690–705. Crossref
66. Liu Y, Málaga-Chuquitaype C, Elghazouli A. Behaviour of beam-to-tubular column angle connections under shear loads. Engineering Structures. 2012 Sep; 42:434–56. Crossref
67. Bursi O, Leonelli L. A finite element model for the rotational behavior of end plate steel connections. In the Proceedings of the SSRC Annual Task Group Technical Session; 1994. p.162–75.
68. Kishi N, Ahmed A, Yabuki N, Chen W. Nonlinear finite element analysis of top-and seat-angle with double web-angle connections. Structural Engineering and Mechanics. 2001; 12(2):201–14. Crossref
69. Garlock MM, Ricles JM, Sause R. Cyclic load tests and analysis of bolted top-and-seat angle connections. Journal of Structural Engineering. 2003 Dec; 129(12):1615–25. Crossref
70. Kukreti AR, Abolmaali AS. Moment-rotation hysteresis behavior of top and seat angle steel frame connections.

Journal of structural Engineering. 1999 Aug; 125(8):810–20. Crossref
71. FluidChe 2017 Available from: http://fluidsche.ump.edu.my/index.php/en/
72. The Center of Excellence for Advanced Research in Fluid Flow (CARIFF) Available from: http://cariff.ump.edu.my/
73. Natural resources products prospects - International Conference on Fluids and Chemical Engineering FluidsChE 2017 Malaysia,). Indian Journal of science and technology. 2017; S2(1).
74. University Malaysia Pahang. Available from: www.ump.edu.my