Recent Trends in Civil Engineering and Built Environment Vol. 4 No. 1 (2023) 220-231

RTCEBE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN :2773-5184

Computational Study of Steel Bracket Connection Subjected To Axial Load

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DOI: https://doi.org/10.30880/rtcebe.2023.04.01.023
Received 06 January 2022; Accepted 15 January 2023; Available online 01 May 2023

Abstract: Steel bracket connection is one of the beam-to-column connection enable shear and moment transmit securely from beam to column. This paper presents the finding of the structural behaviour of steel bracket connections with different number of bolts, the arrangement of bolt and unsymmetrical bolt arrangement due to loosen bolts were analysed using LUSAS software. The connections were modelled in 3D. Thick shell element was assigned to the steel column, steel beam and steel plate. The bolts were modelled as the nonlinear thick beam. Nonlinear FEA with material nonlinearity was used to predict the capacity of the steel bracket was increased with the increment of bolts. Meanwhile, structural behaviour and stress distribution of steel bracket connection with loosen bolts are significant different with others and gained lower capacity.

Keywords: Steel Bracket Connection, Bolted, Finite Element Analysis

1. Introduction

The usage of steel in the construction industry has increased over the years because the characteristic of steel material was found to be far better than other construction materials[1]. The steel structures usually construct by assembling the structural member, so the connection of the steel structure is important for the performance of the whole structure. The option of the connections may apply bolting, welding or riveting for the assembly of the complete structure[2]. Steel bracket is one of the rigid connections as a bolted beam-to-column connection, the common failure that will occur at bolted beam-to-column connections are shear out-failure, bearing failure and pull-out failure[3]. From the inspection conducted by previous study, the obstacle met for the maintenance work in bolt connection is due some damage, releasing clamping force is the most frequent problem following by corrosion, missing bolt and missing nut. The bolt connections under certain service periods may experience corrosion, it may cause the bolt to loose[4].

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In construction industry, steel is one of the most favorable materials used in construction industry. Compare to reinforced concrete structures, steel structure is much lighter in weight that can reduce the burden of the foundation. In fact, the strength to weight ratio of the steel is large which indicates that the range of the plastic deformation zone is large before the failure of steel occurs. Large plastic deformation zone of material certainly capable to construct massive structures such as airports, industrial plants, high rise buildings or bridges[5]. However, there is a risk for the construction of steel structure during transportation process of structural element, the risk of causing damage is high when the distance from manufacturing factory to construction site is far[6].

Steel bracket connection is one of the beam-to-column moment connections to enable shear and moment transmit securely from beam to column. Figure 1 shows the stiffened steel bracket connection under axial applied on it [7]. The performance in every connection part defines the stability of the whole structure due to failure is more likely in connection instead of main structural members, lack of strength within connection which contribute to failure can be called as "weak link"[8]. In standard code of practice Eurocode 3 as known as EC3, there is no proper theoretical approach for the design of moment connection, but there is the equation stated in EC3 for the design of combined shear and tension for individual fasteners such as bolt and nut.

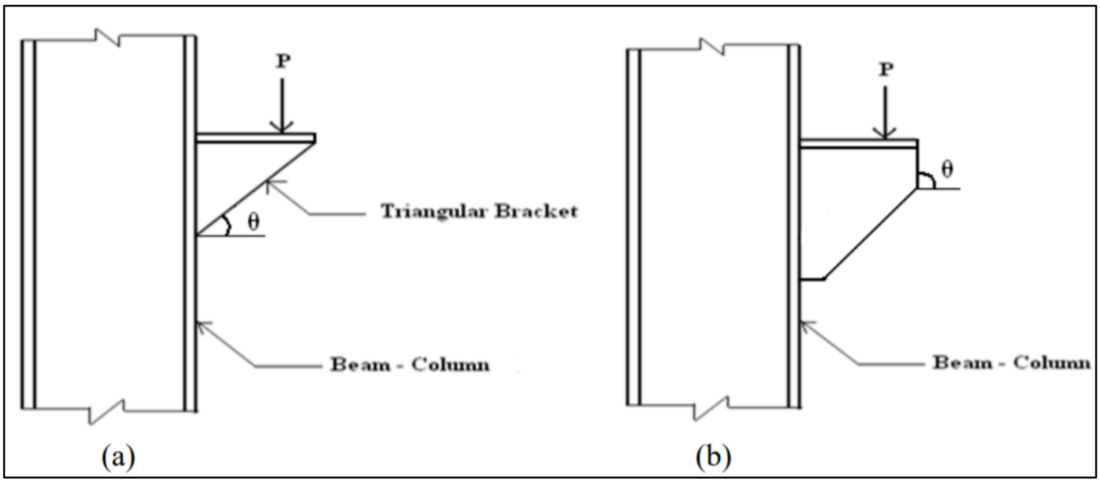

Figure 1: Steel bracket connection[7]

This paper interprets the structural behaviour of steel bracket connection subjected to axial load by using LUSAS finite element analysis. From this parametric study, the optimum bolts arrangement for steel bracket connection was established according to the findings from this project. This project also provide understanding about the effect of loosen bolts on structural behaviour of steel bracket connection.

2. Methodology

The methodology of this paper is explained precisely on the approach to conduct this parametric by using finite element analysis.

2.1 Finite Element Analysis

This study applied LUSAS software to develop three-dimensional finite element analysis to predict the structural behaviour of steel bracket connection. LUSAS software is a structural analysis system which is widely used by the community of engineers to solve the engineering analysis problem. LUSAS finite element analysis provides accurate results for linear and nonlinear stress, dynamic, and thermal problems[9].

The analysis by using LUSAS are divided into 3 stages, modelling, running analysis and viewing results. Modelling is known as pre-processing to create geometry of the model, define physical properties such as material, loading and support. The function of geometry is to create the model in graphical representation which consists of points, lines, surfaces and volumes. After that, assign materials, loading and support are referred to the attributes. Before running the analysis, the load cases will define whether the analysis is either linear or nonlinear analysis. Once the modelling process has been finished, the processing of analysis will be performed by LUSAS Solver. The results will be generated for the next stage, post processing. There are many types of results facilities that are available in LUSAS, the result can be viewed in various ways, such as deformed mesh, graph, contours, envelopes and vectors[9].

2.2 Theoretical Design of Steel Bracket Connection

The design of steel bracket connection is referred to the standard code of practice for safety provision. Therefore, the design of the bolt connections is referred to Eurocode 3, according to BS EN 1993-1-8: Clauses 3.1.1, the yield strength and the ultimate tensile strength of the bolts. In addition, the design of the positioning of holes for bolts and rivets will based on BS EN 1993-1-8: Clauses 3.5. From BS EN1993-1-8: Clauses 3.6.1 provide the design resistance for individual fasteners subjected to shear and tension. Some prediction of bolt capacity can be done by generated manual calculation based on the design approach in Eurocode (EC3). Other than that, all the characteristic for structural materials such as yield strength of steel are taken the standard value stated in Eurocode 3. For this study, the bolts of the bracket connection are considered as combined shear and tension. Therefore, the capacity of bolt connections should design beyond the applied load on steel bracket connection[10]. The equation of bolt shear resistance is

$$F_{v,Rd} = \frac{a_v f_{ub} A}{\gamma_{M2}} \; Eq. 1$$

where a_v and γ_{M2} are default value from EC3, f_{ub} is ultimate tensile strength and A is shear area of bolt. The equation of bolt tensile resistance is

$$F_{t,Rd} = \frac{k_2 f_{ub} A_s}{\gamma_{M2}} \; Eq. 2$$

where k_2 and γ_{M2} are default value from EC3, A_s is tensile area of bolt. The equation to calculate reaction of bolt for tensile force is

$$F_{T,Ed} = P.e.y_1/2\Sigma y^2 \; Eq. 3$$

where P is axial load, e is eccentricity, y_1 is maximum vertical distance from bolt to load point. The equation to calculate reaction of bolt for shear force is

$$F_{v,Rd} = P/No. of\ bolts \; Eq. 4$$

The equation of combined shear and tension which stated in EC3 is

$$\frac{F_{v,Ed}}{F_{v,Rd}} + \frac{F_{t,Ed}}{1.4F_{t,Rd}} \leq 1.0 \; Eq. 5$$

The fixed parameters and the specification of the modelling of this study are summarized in table 1, Figure 2 illustrates the specification of steel bracket connection.

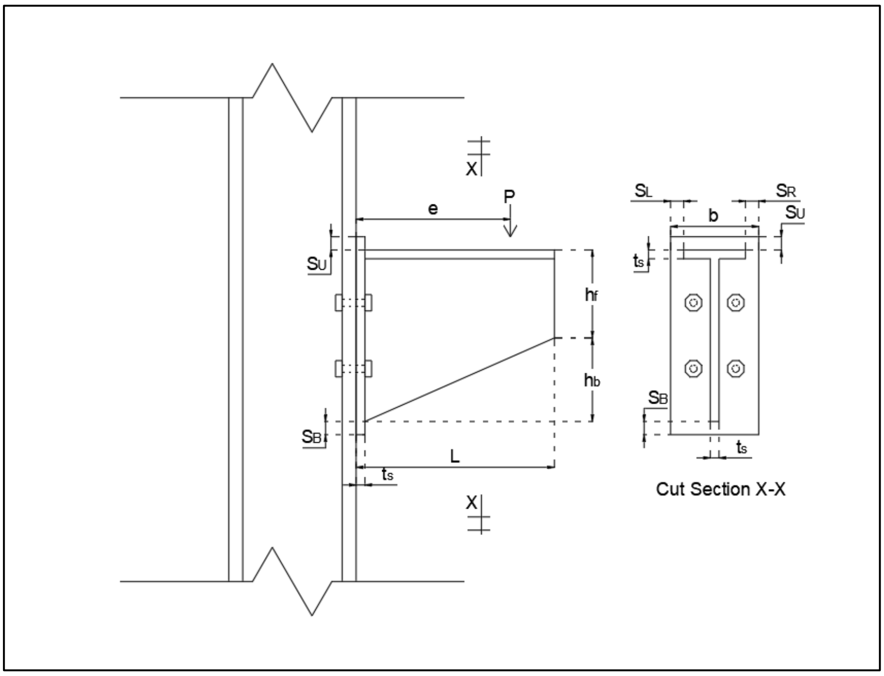

Figure 2: Specification of steel bracket connection

Table 1: Fixed parameters

Elements	Specification	
Column	UC Column 254x254x73	
Bolt	Bolt class = 4.8 F_{yb} = 320N/mm^2 F_{ub} = 400N/mm^2 Diameter = 16mm A = 201 mm^2 As =157 mm^2	
Steel bracket	e = 350mm	L = 450mm
	S_U = 30mm	h_f = 200mm
	S_B = 30mm	h_b = 190mm
	S_L = 30mm	d = 450mm
	S_R = 30mm	t_s = 10mm
	e_1 = 75mm	e_2 = 50mm

2.3 Finite Element Modelling

A total of 13 specimens of steel bracket connections were performed in finite element analysis accordingly. These models were categorized series A,B and C due to different parameters for the design of steel bracket connection, the models are shown in figure 3,4 and 5 respectively. The models of series A are focused on the structural behaviour of steel bracket connection with different number of bolts, all models have same spacing between bolts as their fixed variable. In series B, each model has their own different arrangement of bolt, the number of bolts is fixed at 2(column) x 4 (row) for all models. Models in series C are the bracket connections with loosen bolt, these models aim to analyse the effect of loosen bolt on the structural behaviour of bracket connection, every model have at least of loosen bolt in different location.

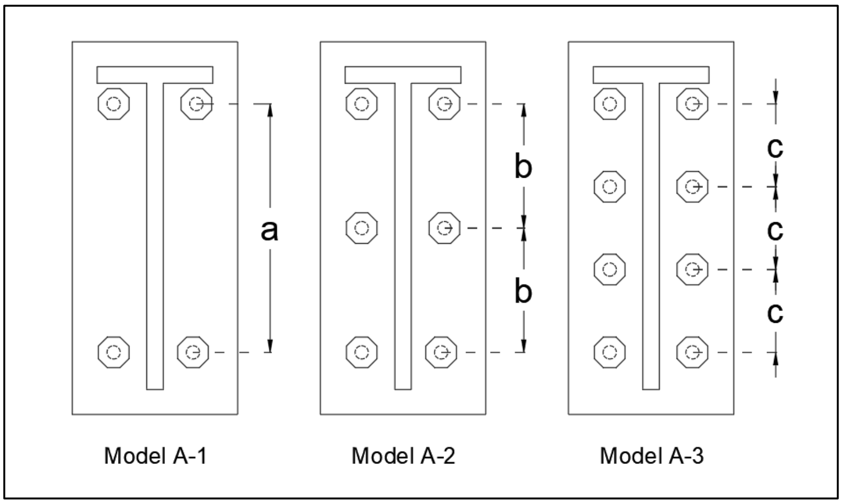

Figure 3: Models of series A

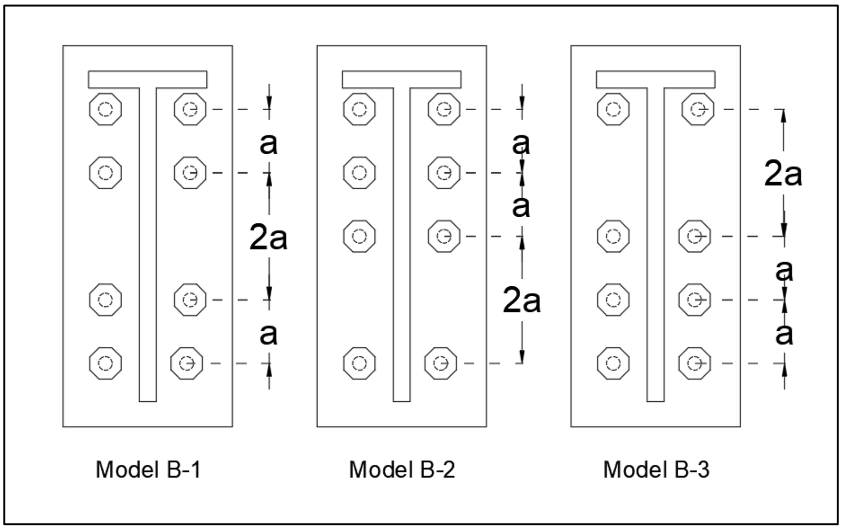

Figure 4: Models of series B

2.3.1 Geometrical Modelling

In preprocessing, geometrical modelling always generally come to first in modelling procedure. For this study, the geometrical features used in geometrical modelling are only points, lines and surfaces but except volumes feature. The main body of column and steel bracket were featured by surface element, bolted connection was featured by line element. For the modelling of steel bracket connection in this study, a gap between the surface of steel bracket and column is necessary to allow the geometry of bolts between column and steel bracket. Therefore, 1mm of gap was specified for all models to simulate actual characteristic of steel connection. In series C, the geometrical features of selected bolt were removed as the modelling procedure to model loosen bolt.

2.3.2 Finite Element Meshes and Elements

The next step of modelling is to assign finite element meshes and elements, This stage is called meshing which consisted of element type, element discretization and mesh type. For the modelling of steel bracket connection, the main body of models discretized by assigning thick shell elements (QTS8). In details, the element size of surface meshes were specified to 50 with allowed transition pattern and irregular mesh.

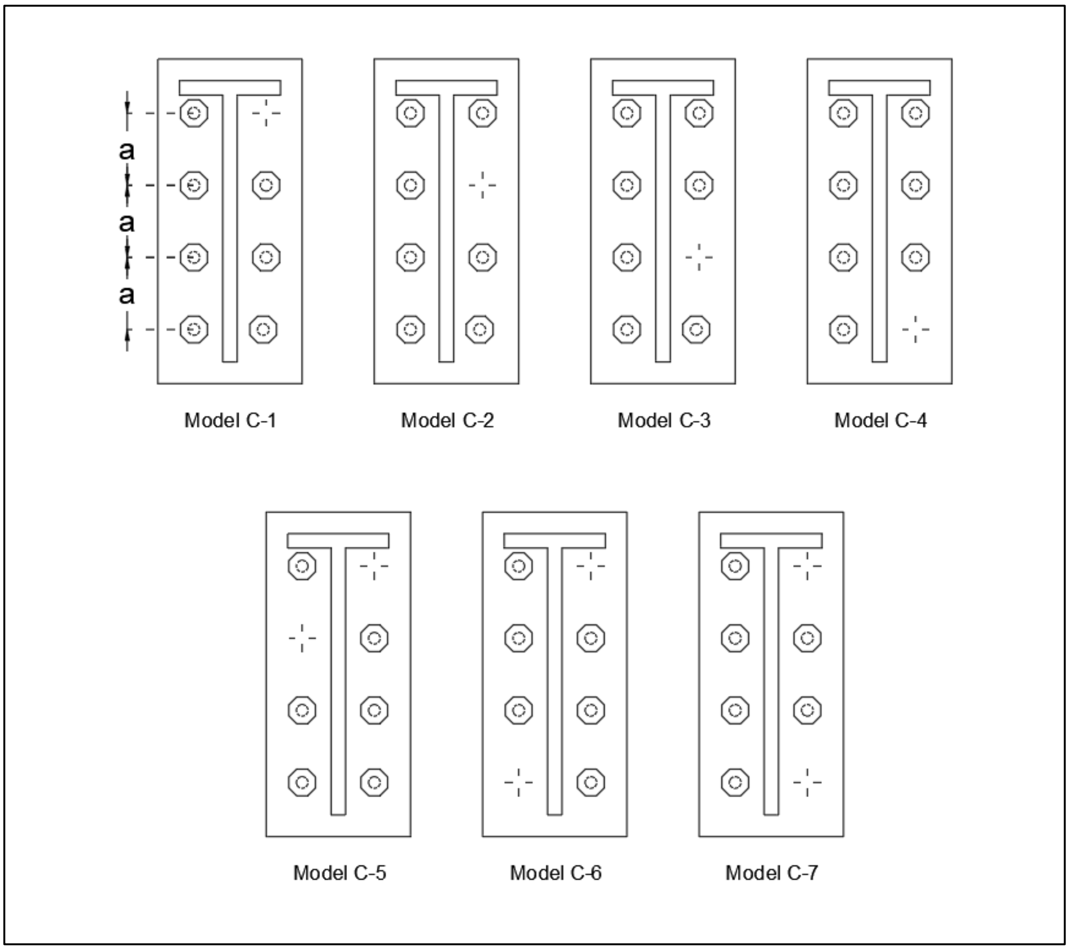

Figure 5: Models of series C

The bolts of the steel bracket connection were modelled as line element between the column and steel bracket. The bolt connection was meshed by 3D engineering thick nonlinear beam element (BTS3). The number of divisions along the line mesh was specified as 1. Apart from that, the geometric of bolt was assigned as 16mm circular solid section, the section properties of 16mm bolt was autogenerated by section property calculator in LUSAS finite element software.

2.3.3 Material Properties

The material properties of finite element model are one of the most influence factor to the analysis of computational study. However, the design values of material coefficient for steel material were stated in Eurocode 3. Therefore, these values were greatly contributed in this study in terms of the design and analysis of steel bracket connection. The modulus of elasticity of steel is 210000 N/mm^2, and Poisson's ratio in elastic stage is 0.3 which were based on the value of Eurocode 3. To generate nonlinear analysis for the modelling of steel bracket connection, plastic material was used to model the ductile yielding of steel. In this study, Von Mises stress potential was applied by inserted 260N/mm^2 of initial uniaxial yield stress. For bolted connection, the material properties were defined as the default value of mild steel.

2.3.4 Boundary Condition

The boundary condition of this study was constant for all models in terms of loading and support conditions, the support condition of the column is pinned-fixed from top to bottom. After that, a concentrated loading was assigned on the steel bracket with the unfactored load of 10kN. In LUSAS finite element software, nonlinear analysis was developed by utilized Nonlinear & Transient definition command to generate incrementation load from linear elastic to non-linear plastic. Automatic load increment was utilized in this study in order to study the structural behaviour of steel bracket connection when the model reached its capacity. Therefore, the load factors will increase continuously with maximum change in load factor of 1 until reach the capacity of the steel bracket connection.

2.4 Finite Element Analysis Validation

The validation of the control steel bracket connection is referred to the Model A-1 from series A. By obtained the capacity of steel bracket connection through manual calculation, the validation can be done by validating the result between theoretical value and finite element analysis result.

3. Results and Discussion

3.1 Structural behaviour and validation of control model A-1

By referring figure 6, the stress contour for the bolted connection in steel surface are obviously seen which indicate that the bolted connection is taking effect between two surfaces. Meanwhile, the overall stress contour is nearly symmetry along y axes.

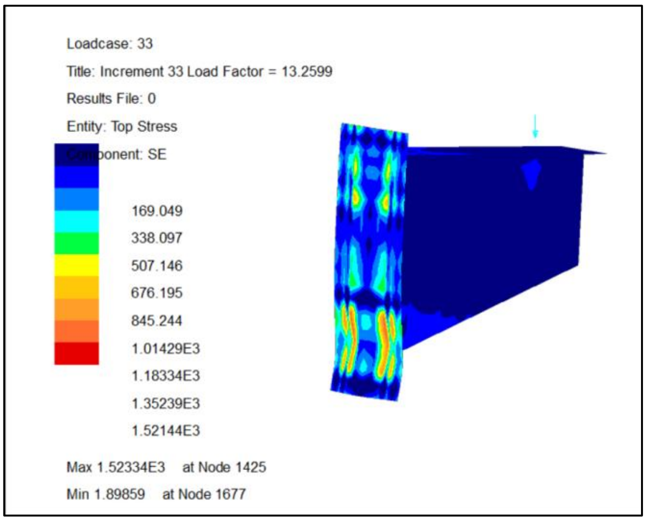

Figure 6: Stress contour in steel bracket connection

The figure 7 shows the deformed pattern of the steel bracket connection when reached its ultimate capacity. As the result shows, the separation between steel bracket connection and column flange was increased especially at top part of steel bracket. Meanwhile, the bottom part of the steel bracket connection is experienced prying force which consider the neutral axis of the connection was lied near bottom part of the steel bracket. Therefore, deformed pattern was similar to the previous study conducted by [11], the upper bolt and end-plate will literally bent when excessive load is applied. Apart from that, the bottom part of steel bracket squeeze against the column flange can be clarify by the principle stated by [10]. According to [10],the result of accurate analysis shows that when tension force formed due to the applied moment on the steel bracket, the compression force is also existed on the most bottom part of connection.

3.2 Capacity of Steel Bracket Connection

By using finite element software, the capacity of the steel bracket connection can be generated in postprocessing phase. In table 2, the capacity for all models of steel bracket connection were tabulated accordingly. As the result shown, the capacity of model A-3 was the highest among all series of models (159kN). However, model C-6 was lacked of strength with the lowest capacity of 106kN.

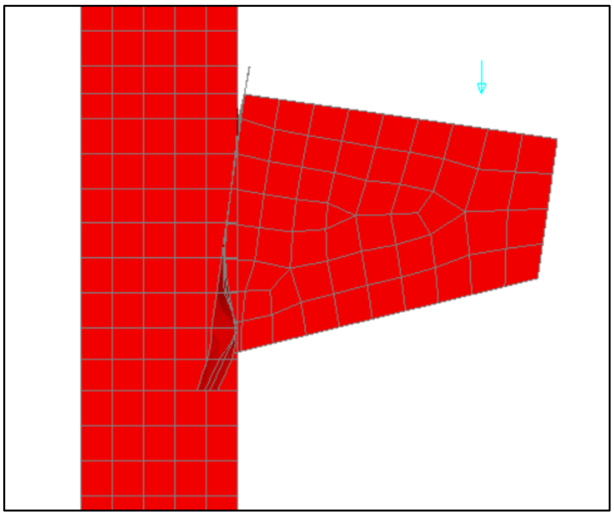

Figure 7: Deformed pattern of steel bracket under ultimate loading

Table 2: Capacity of steel bracket connection

No.	Models	Maximum Load factor	Maximum Capacity (kN)
1	A-1	13.3	133
2	A-2	14.7	147
3	A-3	15.9	159
4	B-1	15.4	154
5	B-2	15.2	152
6	B-3	15.2	152
7	C-1	13.1	131
8	C-2	15.6	156
9	C-3	15.3	153
10	C-4	13.3	133
11	C-5	12.5	125
12	C-6	10.6	106
13	C-7	10.9	109

3.3 Load Versus Displacement

This section is shown the extracted output of the steel bracket connection for each model regarding to the displacement. The maximum displacement of the steel bracket connection is summarized in table 3. Apart from that, the graph of load versus displacement for all models are shown in this section accordingly.

3.4 Stress Distribution and Deformed Pattern

The stress distribution of the steel bracket connection presents by the stress contour combined with deformed pattern under existing load. The structural behaviour in terms of stress distribution for series A and B are nearly identical which can refer to figure 6. The stresses for models in series A and B were distributed in symmetry pattern reflected to y-axes. However, in series C, the stress contour and deformed meshes were totally different within the model in same series. In series C, the deformed pattern of the models was likely swayed to one side, so all the models were deformed in various ways as shown in figure 8, 9, 10 and 11.

Table 3 Displacement of steel bracket connection under ultimate load

No.	Models	Maximum Displacement (mm)
1	A-1	2.98
2	A-2	26.92
3	A-3	156.55
4	B-1	4.63
5	B-2	15.63
6	B-3	14.96
7	C-1	44.14
8	C-2	157.04
9	C-3	80.92
10	C-4	48.86
11	C-5	22.52
12	C-6	55.62
13	C-7	20.05

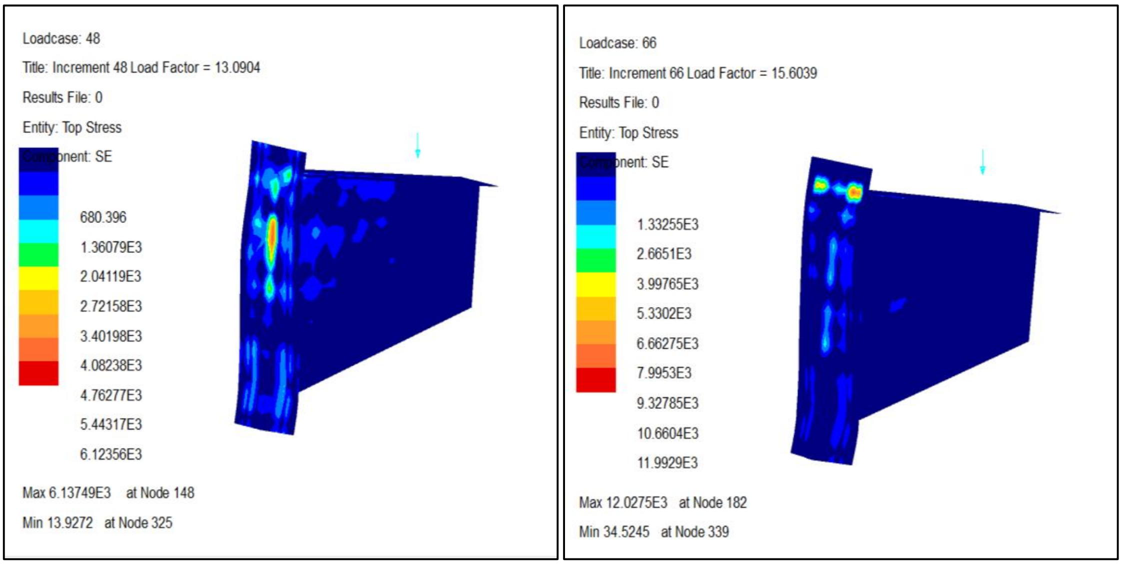

Figure 8: **Stress contour and deformed mesh for model c-1 and c-2-in max. load case**

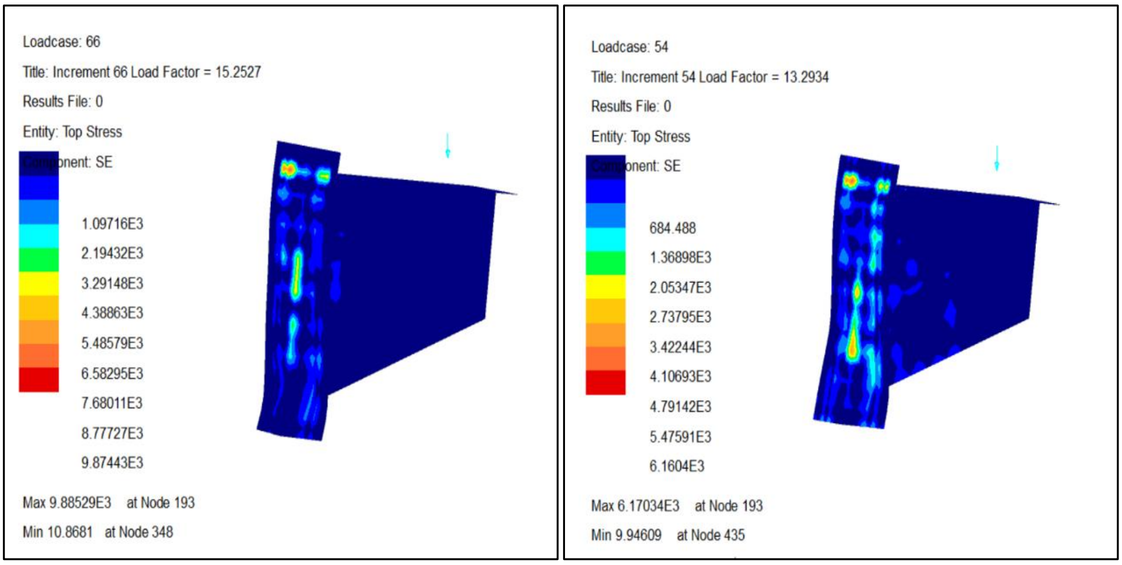

Figure 9: Stress contour and deformed mesh for model c-3 and c-4-in max. load case

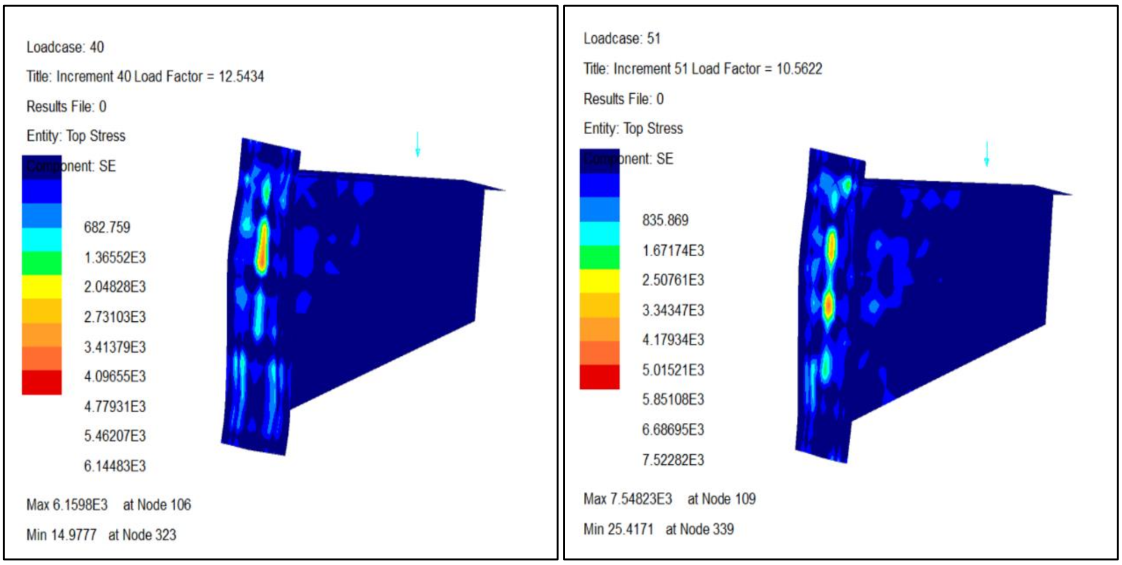

Figure 10: Stress contour and deformed mesh for model c-5 and c-6-in max. load case

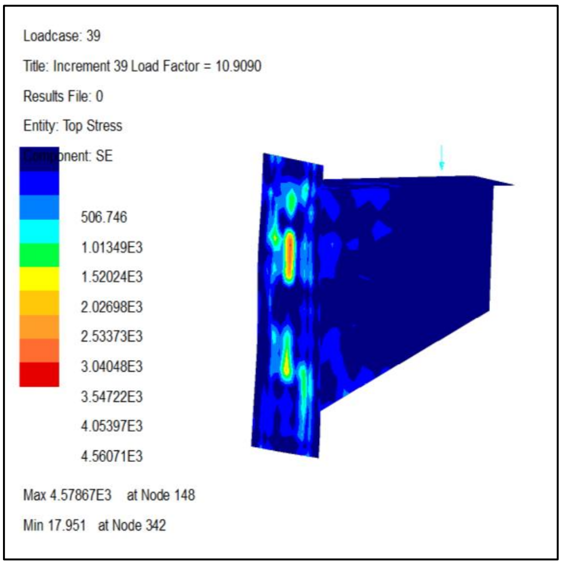

Figure 11: Stress contour and deformed mesh for model c-7 in max. load case

3.5 Comparison of parametric study

This study is focusing on few parameters in order to determine the optimum arrangement of bolts for steel bracket connections. When the results were obtained, some discussion and prediction can be made by relating some engineering principle with the finite element analysis result.

3.5.1 Effect of Number of Bolts on Steel Bracket Connection

The maximum capacity for model A-1, A-2 and A-3 are 133kN, 147kN and 159kN. Therefore, the results in series A are achieved the logical expectation with the statement of increasing number of bolts will induce the capacity of connection. However, the strength of the model A-2 and A-3 did not increase dramatically when number of bolts were added. From the results, it is fair to say that the capacity of the steel bracket connection may not fully governed by the bolt connection.

3.5.2 Effect of Bolt Arrangement on Steel Bracket Connection

In series B, the number of bolts were remained constant for all models and with different bolt arrangement. Model A-1 was added in this comparison due to this particular model had same number of bolts with the model in series B. In comparison, model A-3 had the highest capacity compare to other models. By ignoring Model A-3 in this comparison, the parameter of bolt arrangement did not produce significant effect in terms of the strength, and the maximum percentage different between three models in series B are less than 2%.

3.5.3 Effect of Loosen Bolt on Steel Bracket Connection

By referring table 3, the first 4 models were modelled in conjunction with the one missing bolt, C-5 to C-7 were the models with two missing bolts. For the comparison within C-1 to C-4 that with only one missing bolts, the capacity of model C-2 and C-3 were obviously higher. By observing the stress contour among the models, the stress was concentratedly distributed at the bolt area especially on upper most and lower most. Therefore, these results indicated that the missing bolts located at intermediate row within the bolt arrangement were not affect much on the overall strength of steel bracket connection. Meanwhile, the existence of the bolts located at the top and bottom were very critical to define the strength of the steel bracket connection. However, the bolt which located at the intermediate row will compensate the stress when the absent of the main upper or lower bolt, eventually, the capacity of the steel bracket will preserve.

Obviously, the capacity for the models which have two missing bolts were lower. Besides that, the deformed pattern of the model will slightly sway to one side due to the unbalance stress distribution as the stress contour shown in figure 8, 9, 10 and 11, so the stress distribution was not efficient.

4. Conclusion

The main objective of this study was to analyse the structural behaviour of steel bracket connection in multiple condition of bolt arrangement under axial load. Therefore, multiple of models were prepared and developed by using LUSAS finite element analysis, and verified the results through theoretical equation in Eurocode 3. Hence, this study can be conclude with the following findings:

- All series of steel bracket connection were modelled by using LUSAS finite element software. The structural behaviour of the steel bracket connection had been analysed by evaluate through the deflection, stress contour and deformed pattern in both linear and nonlinear analysis. Especially for the deformed pattern of control steel bracket, the deformation due to prying forces is able to validate with study conducted by [11].
- The optimum bolts arrangement for steel bracket connection are model A-3 which have the characteristic of constant spacings between each row.
- The effect of loosen bolt no doubt will reduce the performance of the steel bracket connection. However, there is only minor reduction in capacity when the loosen bolt is located at the intermediate rows.
- Increasing number of bolts certainly will induce the strength of the steel bracket connection as expected.

Acknowledgement

The authors would also like to thank the Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia for its encouragement.

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