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Finite Element Parametric Study of Bearing Strength of Unconfined Cold Formed Steel Bolted Connection

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Abstract. Investigation on unconfined connection with bolts of cold formed steel (CFS) is recommended in the commentary of North American cold form steel specification. This study is focused on ultimate bearing strength of unconfined bolted connection of CFS. Unconfined bolted connection model was developed and analyzed using ANSYS Workbench software and verified by experimental data of Australian Research Council funded laboratory test. Unconfinement and edge distance are not considered in American Iron and Steel Institute (AISI) equation for bearing strength of bolted connection of CFS. Study was conducted on the verified model for varying thickness, from 0.5 mm to 1.5 mm range and edge distance to bolt diameter ratio ranging from 0.5 to 2.5. Crimpling of unconfined plies in finite element model were exactly matched with experimental failure mode. For different thickness, bearing capacity was found in positive linear trend. Comparison between CFS bolted connection strength from FEM and general equation of AISI shown the ineffectiveness of the equation in case of unconfined plies. AISI equation predict ultimate bearing strength almost twice than found from FEM. In case of edge distance to bolt diameter ratio when the value is reduced less than 1 ultimate bearing strength falls drastically. A minimum edge distance to bolt diameter ratio of 1 is recommended from this study in case of unconfined bolted connection. Equation of Eurocode for CFS Bolted connection is not also adequate for unconfined plies as found unconservative from this study.

Keywords: Bearing Strength, Cold-formed Steel, Finite Element Model, Bolted Connection

1 Introduction

In recent years Cold Formed Steel Construction is becoming popular as a durable, reliable and cost-effective option for mid-rise and low-rise building projects. This light-frame construction and design is mainly done according to AISI and Eurocode for CFS [1-3]. But, as a relatively new construction technique than Hot Rolled Steel (HRS), CFS construction guidelines need updates based on new experimental and numerical investigations. Equation 1 is being used to calculate nominal bearing capacity of cold-formed steel connections with bolts provided in the North American standards are based on in contact sheet connections test results where the plies were fixed in the perpendicular direction [4]. Tightening in a double shear bolted connection ensures that the bolt head

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and nut are in face to face with the outer sheets preventing the inner sheet's ability to buckle or distort in perpendicular direction [5, 6].

$$P_n = Cm_f dtF_u \tag{1}$$

where,

m_f = factor for modification
C = factor of bearing
t = uncoated thickness of sheet
d = bolt diameter(nominal)
F_u = strength of sheet in tension

Table 1. Factor of Bearing

Thickness, t	d/t	C
0.024 ≤ t < 0.1875	d/t > 22	1.8
	10 ≤ d/t ≤ 22	4− 0.1(d/t)
	d/t < 10	3.0

Table 2. Modification Factor

Bearing Connection	m_f
Single-shear and outer sheets of double-shear connection with washers	1.00
Single-shear and outer sheets of double-shear connection without washers	0.75
Inner sheet of double-shear connection with or without washers	1.33

Recent design methodology neglects a condition where the ply is not prevented from crimpling. These situations are certain in applications including truss members and frame braces [7]. However, investigations that have been conducted on bolted connections showed the crimpling failure, are very few. J3(a) section of the commentary to AISI S100-16 (AISI 2016a) specified the need for laboratory testing to determine the strength of connection with bolts where the plies are not in face to face. Experimental study on unconfined bolted connections, focusing on a limited number of design parameters highlights the need for further research in this area [8].

2 Modelling with FEM

FEM model shown in Fig. 1 and analysis was conducted with ANSYS Workbench 2021 R2 according to the experimental setup of Australian Research Council funded laboratory test. Specimen data of 4R2A15 was used for validate the finite element model. Specimens that were tested, single-bolted and double-shear connections, where the dimensions of the internal sheets and bolt hole's location was specified to confirm that governing mode of failure is bearing. Inner sheet width was 100 mm to avoid fracture at critical section in tension, and the bolt hole distance from the edge in the loading direction was at least 50 mm to prevent shear-out failure. Each specimen was connected by a bolt in such a way that the bolt head and nut were not in contact with the outer sheets [8]. Edge distance was reduced further as a parameter to find the limit of the ratio between edge distance and bolt diameter ensuring crimpling failure of the sheet.

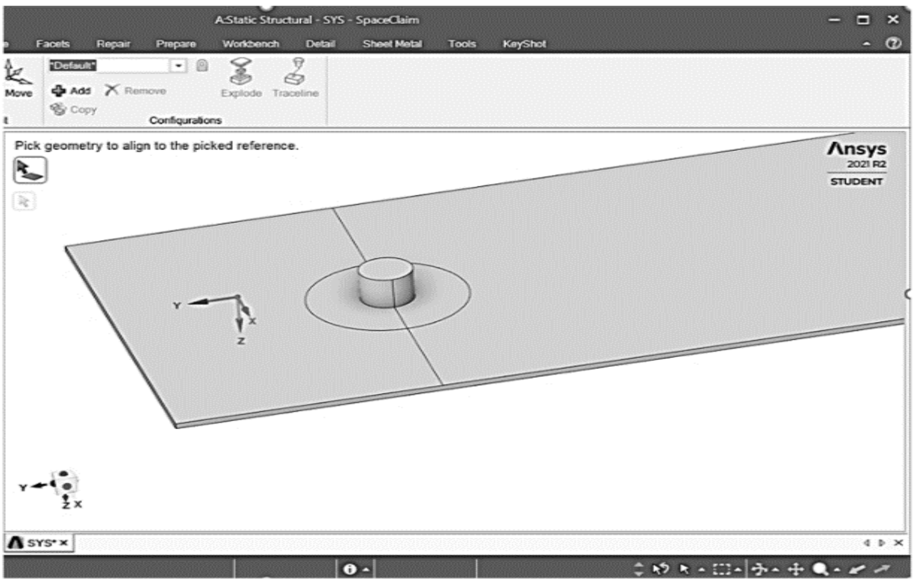

Fig. 1. ANSYS Model

Bolt diameter was used 12 mm for parametric study as commonly used in CFS [8]. SOLID 185 and SOLID 186 elements of ANSYS Workbench were used for the three-dimensional model with 8 nodes for linear and 20 nodes for quadratic analysis accordingly. Refinement order 3 was selected for very fine meshing for close surface of hole and bolt surface. Bolt and hole attached surface are selected as contact and target for fully bonded contact. Contact and target were coupled so that any differential displacement cannot occur in the hole surface points. Far end of the plate was kept fixed, and side displacements were kept zero in Z direction (perpendicular to the plate).

2.1 Strain Controlled Test in FEM

The numerical test was conducted with stepping in strain. For fetching crimpling behaviour, bolt top surface was given 2 mm displacement in 1st step when the bottom surface was not displaced. In 2nd step of analysis both top and bottom surface were given displacement of 5 mm. These two steps analysis initialized the crimpling, working as imperfections. Auto time stepping was kept on and solver type set to direct. Large deflection was always kept on for both material and geometrical nonlinearity.

2.2 Model Verification

Crimpling behavior of output of finite element model was matched with experimental failure mode shown in Fig. 2. Ultimate bearing load from finite element model was very close to experimental value to conduct further parametric study shown in table 3 and Fig. 3.

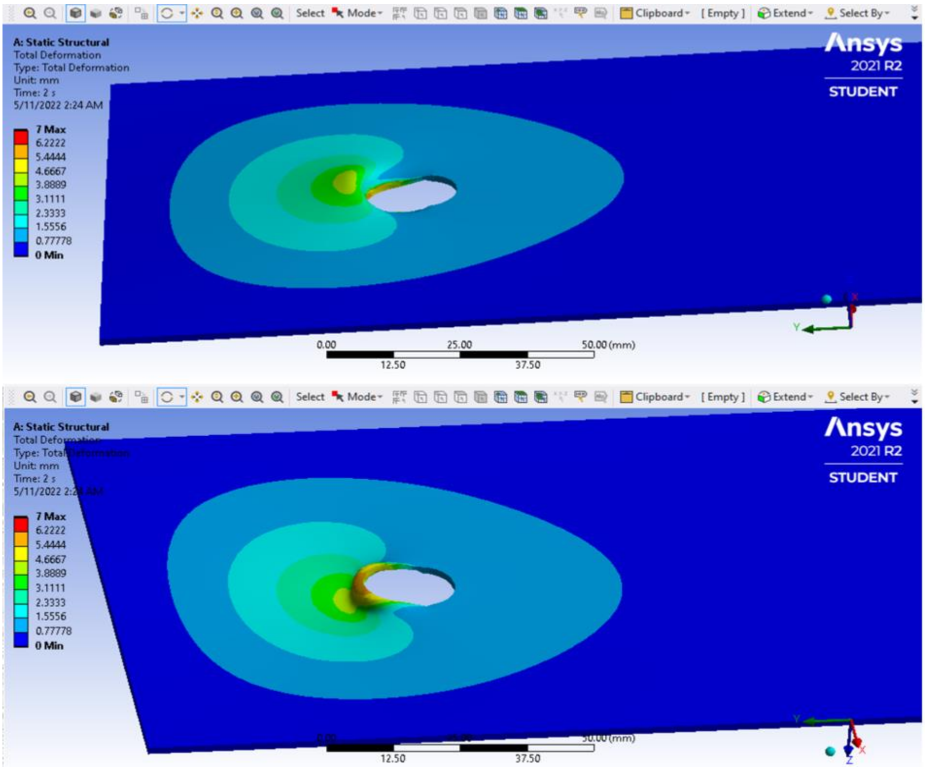

Fig. 2. Finite element failure mode

Table 3. Comparison between FEM and Experimental Load

Ultimate Load Experimental Data (kN)	Ultimate Value form FEM Analysis in ANSYS (kN)	Ratio of FEM /experimental
19.72	20.51	1.039

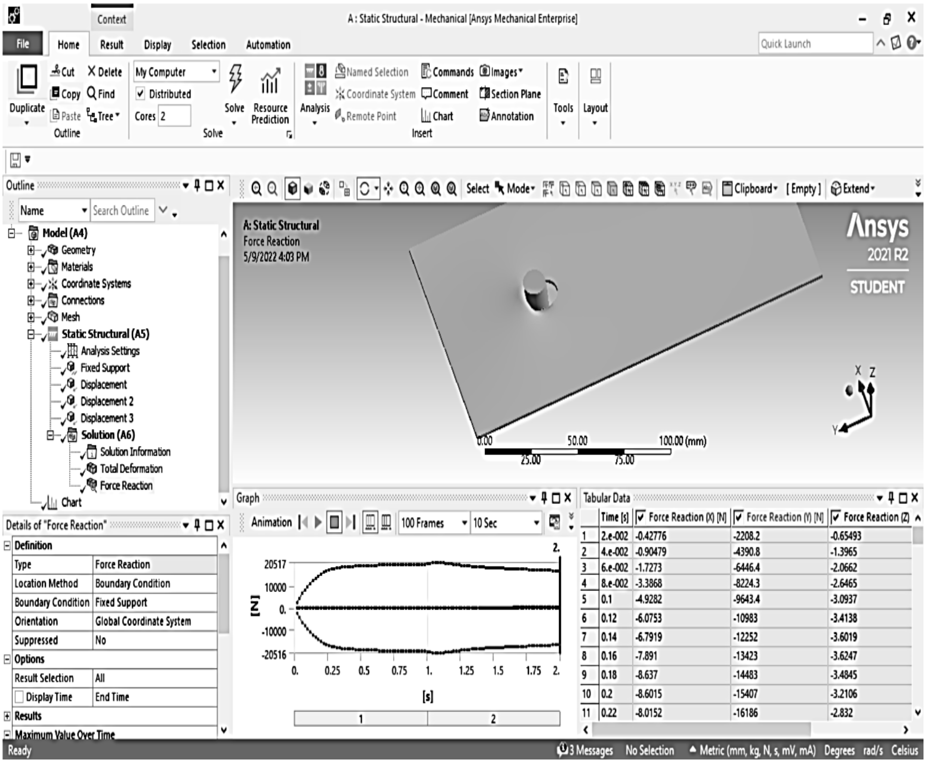

Fig. 3. Finite element load steps

3 Parametric Study Result and Discussion

Using the validated model CFS sheet thickness was taken as first criteria to be checked. As edge distance limit for bearing failure was not fixed in AISI, edge distance to bolt diameter ratio was also taken as a parameter. Parametric finite element model load results are listed in table 4.

Table 4. Finite Element Load Outputs for Parameters

		Ultimate load in KN				
Plate Thickness (mm)		1.5	1.25	1	0.75	0.5
Edge distance to Bolt Dia Ratio, L_c/d	0.5	13.41	11.32	8.57	6.41	4.18
	1	19.12	15.08	11.77	8.45	4.80
	1.5	20.36	15.71	12.38	8.77	5.40
	2	21.07	16.42	12.17	8.63	5.28
	2.5	22.92	16.96	12.32	8.70	5.44

3.1 Ultimate Bearing Strength Relation with CFS Plate Thickness

Fig. 4 depicts that ultimate bearing strength is varied with plate thickness almost linearly correlated.

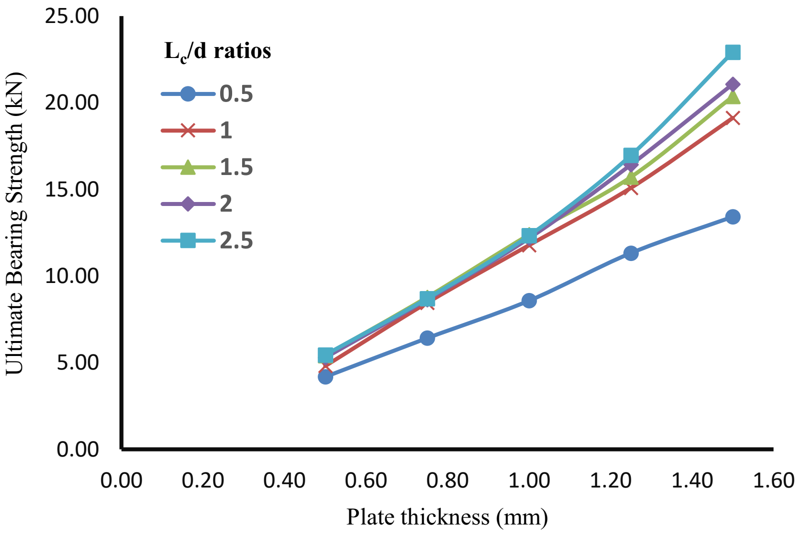

Fig. 4. Ultimate Bearing Strength Vs Plate Thickness Graph for 5 different L_c/D ratio

3.2 Ultimate Bearing Strength Relation with Edge Distance Ratio

Fig. 4 clearly shows that bearing strength value remains almost same for edge distance ratio greater than 1. But Strength decreases significantly when ratio is less than 1. Fig. 5 ensure the trend more distinctly that edge distance ratio 0.5 curve deviate from others by a significant value.

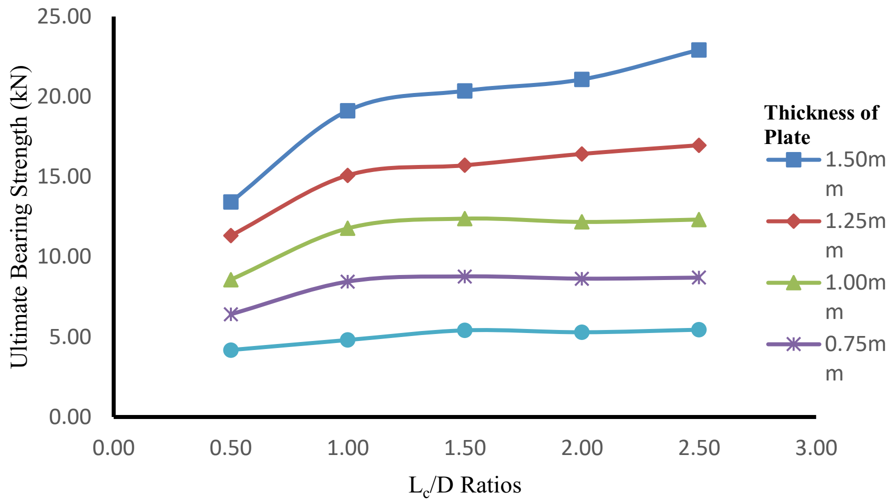

Fig. 5. Ultimate Bearing Strength Vs L_c/D Graph for 5 different plate thickness

3.3 Ultimate Strength from Finite Element Model, AISI and Eurocode

Fig. 6 depicts AISI, Eurocode and FEM curve for ultimate strength that are plotted for largest edge distance ratio of this study. Even for the largest value of edge distance ratio AISI equation and Eurocode equation overestimate strength for unconfined connection. AISI deviate almost twice in total range whereas Eurocode deviate by 50% for small sheet thickness.

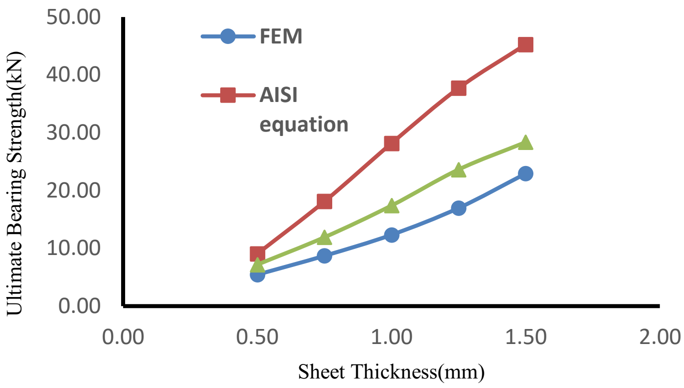

Fig. 6. Ultimate Bearing Strength vs Sheet Thickness from FEM, AISI and Eurocode

4 Conclusions

Bearing strength increases with plate thickness linearly, but increased thickness makes the cold work difficult. So, thickness and strength have to be balanced for economic design. AISI and Eurocode equations for ultimate bearing strength have to be modified for unconfined plies. Minimum edge distance to bolt diameter ratio is suggested 1 from this study as fall in bearing strength found. Further study can be conducted taken serviceability, temperature and other relevant parameters in consideration.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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