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Technical Note

BEHAVIOUR OF BOLTED COLD FORMED STEEL CHANNEL TENSION MEMBERS

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ABSTRACT

Cold formed steel channel sections bolted at the end supports are widely used almost in all construction fields to form integral part of structural members. In order to promote the effective utilization of cold formed steel structures, it is important to have a detailed investigation on the behaviour of cold formed steel members. This paper investigates bolted channel members subjected to tension which influences the shear lag effect. The thickness of the cold formed steel sheet was 2mm. Twelve plain channel members with different dimensions are bolted to gusset plate using bolts of 10mm diameter, are tested in an Universal Testing Machine. All the specimens were tested till failure. The ultimate load carried by the specimens were compared with the theoretical load capacity by various codes such as AISI 2007, AS/NZS 4600, BS 5950-part 5 1998 and also with the load carrying capacity predicted by ANSYS.

Keywords: Cold-formed steel; channel sections; tensile strength; shear failure; bolted connection.

1. INTRODUCTION

Cold-formed steel structural elements are widely used as structural elements in roofs, decks, wall panels, trailer bodies, agricultural equipments, aircrafts, etc. The study conducted with detailed investigation of the shear lag effect on bolted cold-formed steel tension members by using different channel sections. The comparisons were made between the test results and predictions computed based on several specifications. In order to study the stress distribution at the various locations of the cross section of specimen, the finite-element software ANSYS was used [1]. The behaviour of cold formed steel members subjected to axial tension and problems are worked out based on various codes [2]. An attempt is made to study the provisions of standards codes for analysis of various sections subjected to axial tension.

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Computer based programmes are developed for the analysis based on the codal provisions [3-6]. A detailed investigation of an experimental and numerical investigation with a primary objective of studying the effect of shear lag on cold-formed steel single and double angles subjected to tension. The actual load carried by the specimen was compared with the theoretical load carrying capacity predicted by various codal provisions and with the load carrying capacity predicted by ANSYS. An empirical equation is proposed to determine the load-carrying capacity of the cold-formed steel angles and the predicted values agrees with the experimental results [7]. The analyzation a numerical investigation of net section failure in stainless steel bolted connections using commercially available FEM software. Based on the experimental results of literature study, the finite element model result has good agreement. The predictions made with net section failure on bolted connections are good and accurate [8]. An experimental investigation on bolted moment connections between single cold-formed channels connected back-to-back at the joints. The use of cold-formed steel sections connected back-to-back at the joints allows simple and effective connection to be formed among cold-formed steel sections leading to improved build ability [9]. The study of shear lag phenomenon in cold formed angles under tension, which are connected on one leg. A new expression for shear lag factor which represents the net section reduction coefficient has been suggested [10]. A experimental research aimed at evaluating the real behaviour of bolted joints in cold-formed steel trusses. By means of tests on single lap joints and on truss sub-assemblies, a theoretical model for joint stiffness was proposed. The formula for the joint stiffness, from which the buckling length of web members was further determined, and validated through a test on a full-scale truss [11].

There were only limited investigations for cold-formed steel members. The present investigation aims to study the behaviour of cold-formed steel channel members under tension.

2. CODAL PROVISIONS

2.1 British standards BS 5950-5:1998 [4]

The tensile capacity P_t of a member,

$$P_t = A_e P_y \tag{1}$$

Where A_e= effective net area of the cross section, mm^2

P_y= design Strength, N/mm^2

$$Ae = \frac{a_1 (3 a_1 + 4 a_2)}{(3 a_1 + a_2)}$$

a_1=Net sectional area of the connected parts, mm^2

a_2=Gross sectional area of the unconnected parts, mm^2

2.2 Australian and new zealand standards AS/NZS 4600: 2005 [3]

The nominal section capacity of a member in tension shall be taken as the lesser of

$$N_t = A_g f_y \text{ and} \tag{1}$$

$$N_t = 0.85\, K_t\, A_n\, f_u \tag{2}$$

whereA_g= gross cross sectional area of the member, mm^2
f_y= yield stress of the material, N/mm^2
K_t= correction factor for distribution of forces = 0.85
A_n= net area of the cross-section, mm^2
f_u= tensile strength used in the design, N/mm^2

2.3 American iron and steel institute AISI 2007 [11]

The tensile capacity P_n of a member should be determined from,

$$P_n = A_e\, f_u \tag{4}$$

Wheref_u= tensile strength of the connected part of a member, N/mm^2
A_e= UA_n and $U = 1.0 - 0.36\, \bar{X} / L < 0.9$ and $U > 0.5$
A_e= effective net sectional area of the member, mm^2
$\bar{X}$= distance from shear plane to centroid of the cross section, mm
L= length of the end connection i.e. distance between the outermost bolts in the joint along the length direction, mm

3. EXPERIMENTAL INVESTIGATION

The specimens were fabricated from cold formed steel sheet of thickness 2mm by press breaking operation. Standard tension tests are conducted on the specimens made from the same cold formed steel sheet to ascertain the properties. Fig. 1 shows the stress strain curve and its properties.

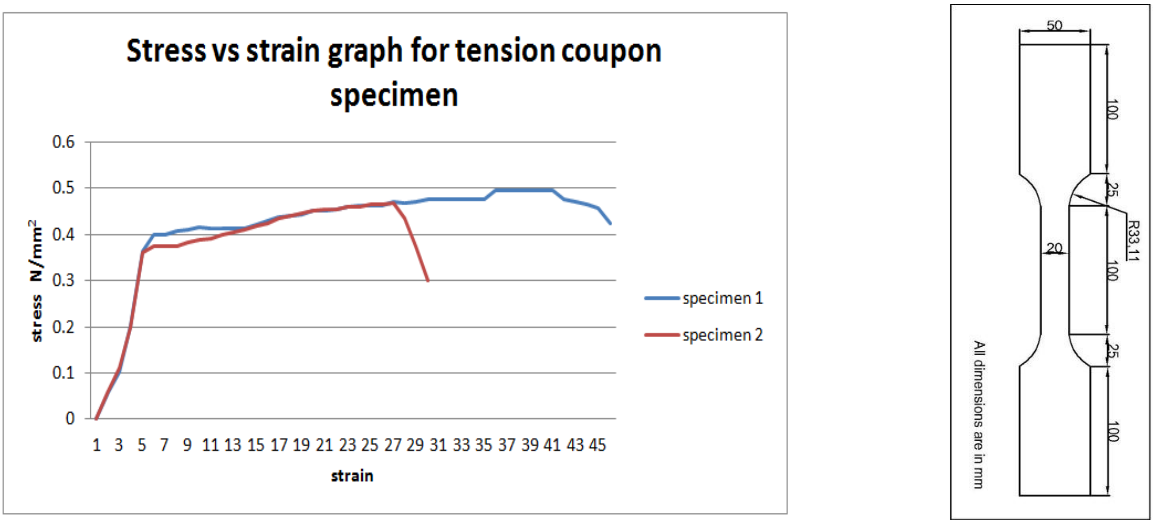

Figure 1. Stress strain graph and tensile coupon specimen diagram

- ✓ Thickness of sheet t = 2 mm
- ✓ Gauge length L_g = 50 mm
- ✓ Modulus of elasticity E = 200000 N/mm^2
- ✓ Yield Strength f_y = 389 N/mm^2

Twelve numbers of plain channels were fabricated from cold formed steel sheet of 2mm thickness. The length of the channel is 500mm for all the specimens. The bolts used for connecting gusset plate and channel sections are 10mm diameter. The gusset plates are manufactured from hot rolled steel of 8mm thickness.. According to the requirement of pitch and edge distance, the length of gusset plate was fabricated. The specimens were tested in the Universal testing machine of 1000kN. Loads are gradually applied with suitable increment from control panels and for each increment of loads corresponding elongation is recorded. The yield, ultimate and breaking loads were observed. The procedure is repeated till all the specimens reaches at their failure modes. The observed yield load and ultimate load of the specimen tested are recorded. Fig. 2 and 3 shows the specimen details and Fig. 4 shows the experimental setup.

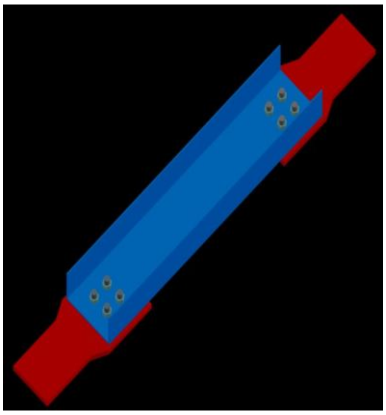

Figure 2. Model of 150x45x2mm specimen

Figure 3. Channel section of 150x45x2mm

Figure 4(a). Experimental setup front view

Figure 4(b). Experimental setup rear view

4. NUMERICAL INVESTIGATION

In order to test the validity of the experimental results, finite element analysis package ANSYS(12.0) was used for the modelling. A non-linear analysis was performed and the materials are assumed to behave as an isotropic hardening material. From the tension test results, the static material modelling was done. The element type used to model the channel specimens is SHELL 63. It is a 4-noded 3 dimensional quadratic shell element. This element has six degrees of freedom at each node. Finite element mesh of size 2x2mm was implied and used in all the simulations. The friction or contact between connected leg of the specimen and the gusset plate was ignored. Fig. 5 shows the meshing of an element and Fig. 6 shows the load applied on the element.

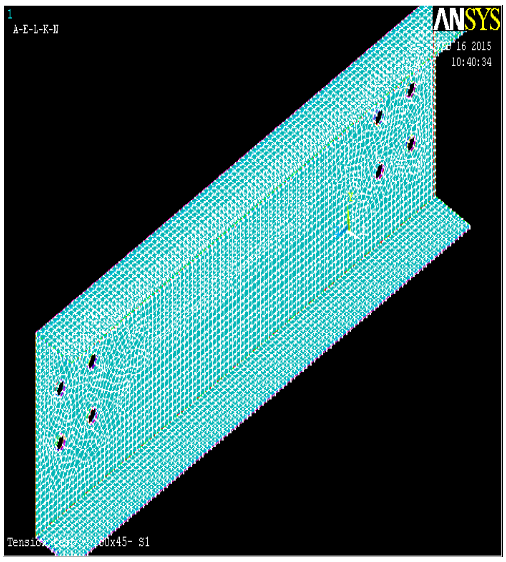

Figure 5. Meshing of an element - 2x2mm

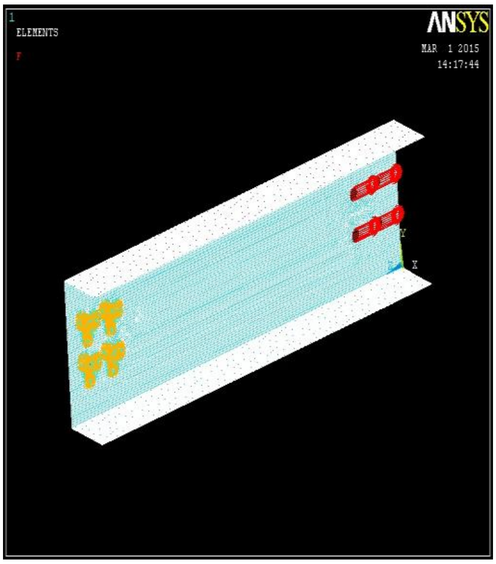

Figure 6. Loads applied on the element

5. RESULTS AND DISCUSSION

The behaviour of cold formed steel channel members were subjected to eccentric loading was studied. The average ultimate load carrying capacity of the specimen were tabulated and compared with the predicted results from codes and with the results obtained from the ANSYS software.

Experimental Investigation

Ultimate Load Carrying Capacity

The ultimate load carrying capacity of all specimen obtained are tabulated in Table 1. It is observed that as the cross sectional area increases, the load carrying capacity increases.

Table 1: Maximum load and its displacement

Sl.no.	Size of the specimen	Avg, Yield load (kN)	Avg. Max load (kN)	Avg. Displacment at max load (mm)
1	100x45x2	29.2	67.50	22.35
2	100x60x2	24.58	69.83	22.70
3	125x45x2	32.98	77.68	25.70
4	125x60x2	32.00	75.45	24.65
5	150x45x2	37.85	80.78	23.00
6	150x60x2	35.08	82.60	24.70

Failure Mode

During the loading process, bending of gusset plates together with channel specimens was observed. A gap was created between the connected leg and the gusset plate. This visible length of gap was usually from end of the channel of the inner most bolts. Mainly, two types of failure are observed namely block shear and net section failure. The modes of failure are tabulated in Table 2. Fig. 7 and 8 shows the mode of failure and Fig. 9 shows the specimen tested to failure.

Table 2: Failure mode of the specimen

Sl. no	Size of the specimen in mm	No. of bolt holes	No. of bolt hole lines	Failure mode
1	100x45x2	2	2	Block shear failure
2	100x60x2	2	2	Net section failure
3	125x45x2	2	2	Block shear failure
4	125x60x2	2	2	Net section failure
5	150x45x2	2	2	Net section failure
6	150x60x2	2	2	Net section failure

Figure 7. Block shear failure

Figure 8. Net section failure

Figure 9. Tested specimens after failure

Load VS. Displacement Graph

The deflections at the maximum load for all the specimens are shown in Fig. 10. From the graph, it is observed that when rigidity of the connection increases the stiffness of the member also increases.

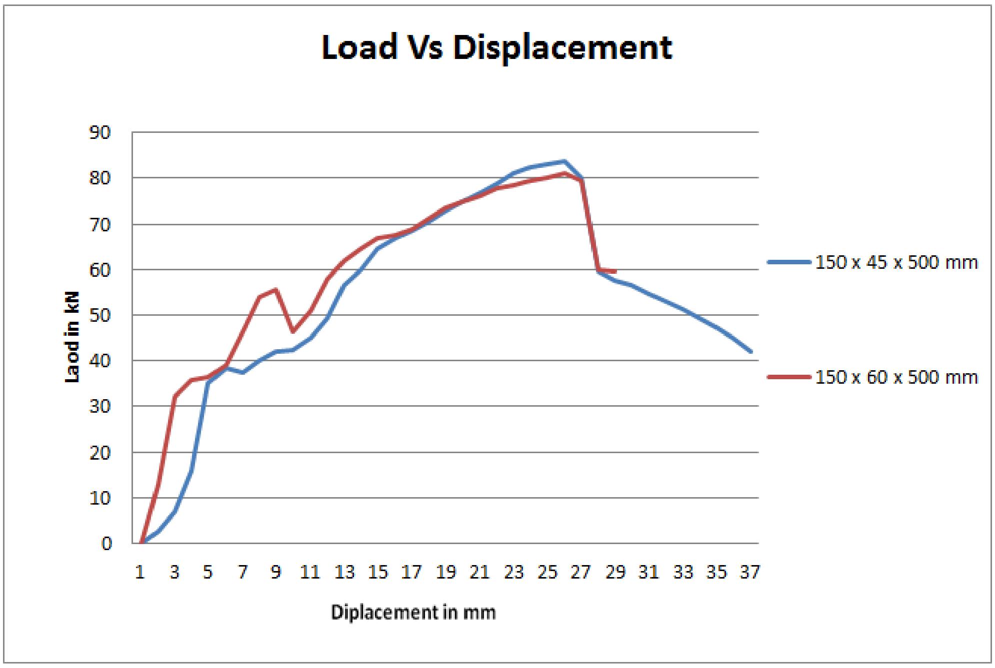

Figure 10. Load VS displacement

6. ANALYTICAL INVESTIGATION

The predicted values from various codes AISI 2007, AS/NZS 4600: 2005, BS 5950- 1998 codes are tabulated in Table 3. It is observed that loads predicted using AISI, AS/NZS, BS are increased by 14.5%, 31.2% and 26.2% respectively than experimental loads. It is also observed that AISI values are almost closer to experimental loads.

Table 3: Design values from code books

Sl.N0	Channel section	Experimental value (kN)	AISI (KN)	AS/NZS (kN)	BS(kN)
1	100 x 45 x 2mm	67.50	70.8	109.8	91.28
2	100 x 60 x 2mm	69.83	77.9	117.8	106.28
3	125 x 45 x 2mm	77.68	85.77	129.59	103.78
4	125 x 60 x 2mm	75.45	94.1	137.5	118.78
5	150 x 45 x 2mm	80.78	100.0	149.45	116.28
6	150 x 60 x 2mm	82.60	109.10	157.22	131.28

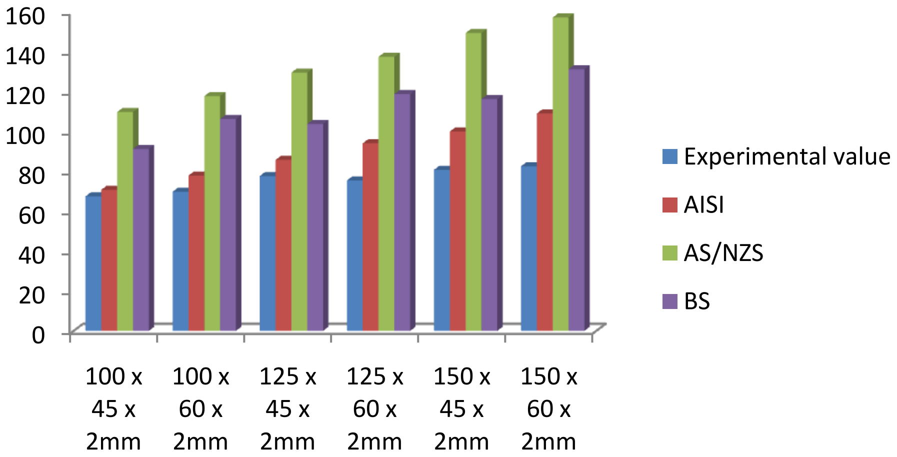

Figure 11. Comparison of Experimental results with various codes

7. NUMERICAL INVESTIGATION

The stress distributions obtained using ANSYS closely agrees with the experimental results within the elastic limit. The Displacement and Von Mises stress distribution is shown in Figs. 12 & 13.

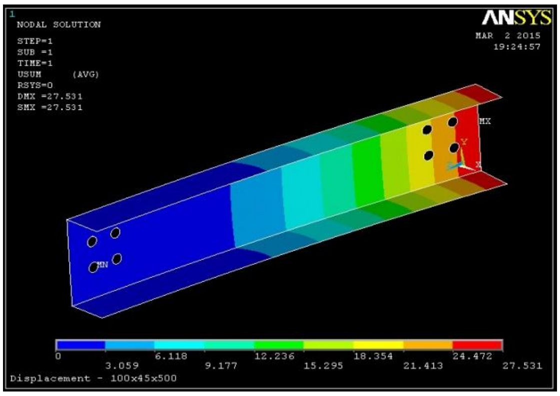

Figure 12. Displacement for 100x45x500

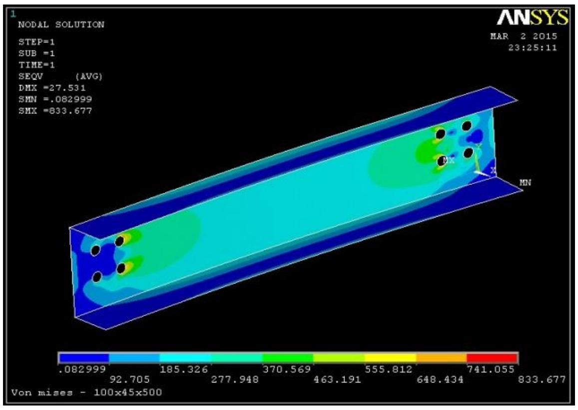

Figure 13. Von mises stress for 100x45x500

Comparison of experimental loads & displacement with ANSYS loads and displacements

Table 4: Comparison of Experimental loads and ANSYS loads

S. No.	SPECIMEN	Load (kN)		Increased percentage difference (%)
		EXPERIMENTAL	ANSYS	
1	100x45x500	67.5	75.05	10.59%
2	100x60x500	69.83	77.81	10.83%
3	125x45x500	77.68	85.69	9.81%
4	125x60x500	75.45	83.91	10.62%
5	150x45x500	80.7	92.55	13.67%
6	150x60x500	82.6	85.61	3.58%

Table 5: Comparison of Experimental displacement and ANSYS displacement

S.No.	SPECIMEN	Displacement (mm)		Increased percentage difference (%)
		EXPERIMENTAL	ANSYS	
1	100x45x500	22.35	27.53	20.77
2	100x60x500	22.70	27.25	18.22
3	125x45x500	25.70	29.35	13.26
4	125x60x500	24.65	27.41	10.60
5	150x45x500	23.00	23.77	3.29
6	150x60x500	24.70	25.29	2.36

From the table, it is observed that ANSYS loads increased experimental loads by an average of 10%. Similarly the displacement obtained from ANSYS increased by 11.42%.

8. CONCLUSIONS

a) Mostly two types of failure namely net section failure and block shear failure were observed.
b) From the load deflection graph, it is observed that ultimate load carrying capacity increases when cross sectional area increases.
c) The loads obtained by various codes increase experimental loads by 14.5% for AISI, 31.2% for AS/NZS and 26.2% for BS standards.
d) Loads obtained from ANSYS increased experimental loads by 10%. Similarly the displacement obtained from ANSYS increased by 11.42%.

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