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Evaluating the Connecting Members of Cold-Formed Steel Angles under the Tension Load

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Abstract

Tension members consisting of single and double angles are frequently used for lateral bracing and as truss elements Tests performed in cold formed steel angles, connected by bolts and submitted to tensile loads are presented. This work presents 108 specimens carried out on tension members fastened with bolts, to calculate the investigation on cold-formed steel. This analysis carries single angle sections of as 2,3 and 4mm and double angles sections under condition such as Lipped were connected same side to gusset plate and connected to opposite side. Comparisons were made between the test results and the predictions based on both the Experimental investigation and analysis. Results also comparisons were made by the International codes BIS, AISI, AS/NZS and BS.

Key words: Tension members; Cold-formed angles; Net section, Block Shear; Shear. Bucking behavior

INTRODUCTION

Light steel framing is referred to as steel frame building constructed with galvanized cold-formed steel sections. As one of the industrialized building systems (IBS), light steel framing has become a popular construction choice in low to medium rise building and residential house construction because it provides numerous advantages as compared to traditional construction methods. Angle tension members are frequently encountered as principal structural members in trusses and lateral bracing system in general construction. The efficiency of angle tension members is reduced due to the coupled effects of connection eccentricity, stress concentration and shear lag. To highlight a few rapid and dry construction, high quality controlled, time and cost saving, accelerating sustainable development by reducing the dependence on timber materials, and minimizing construction wastes.

Types of failure mode in connections

Longitudinal shear failure of sheet (Type I).

Bearing failure of sheet (Type II).

Tearing failure of the sheet (Type III)

Shear failure of bolt (Type IV).

OBJECTIVE OF THE STUDY

To find Ultimate load carrying capacity.

Graphs between load vs Deflection and Mode of Failure Comparison between International codes BIS, AISI, AS/NZS and BS.

Graphs between Experimental results with various International codes:

REVIEW OF LITERATURE:

The results from one of the first significant research projects on cold-formed angle columns is presented by Popovic et al. (2012). The research provided several fixed and pin-ended column tests and residual strain as well as initial geometric imperfection measurements. Another substantial work has been published by Young (2013). A series of fixed-ended cold-formed slender angle columns is presented therein (width-to-thickness ratio ranged from 35.8 to 57.9). Both the latter studies compare the results with the American and Australian/New Zealand design standards.

Landesmann et al. (2014) also do not incorporate bolted connections into the experimental investigation of cold-formed equal-leg angle sections. However, their study should be highlighted, since several investigations are implemented. Between the results, initial imperfection measurements, load-displacement equilibrium paths, and failure mode configurations are included therein. The column specimens' b/t ratios are comprised between 32 and 58Munse and Chesson (1998) studied riveted and bolted joints and examined factors that reduce net section capacity, conducted numerous experiments on various specimens and connection details. Prior to these studies, tension member capacity was based solely on gross section yielding or net section rupture. Maiola et al. (2002) Structural Behavior of Bolted Connections in CFS Members, Emphasizing the Shear Lag Effect experimental investigation of bolted connections in cold-formed angles (either equal or unequal legs) and channel members (1.55–3.75 mm thickness), and an evaluation of the structural behavior of the connections with identification of the corresponding failure modes, with emphasis on the tensile capacity of angles and channels.

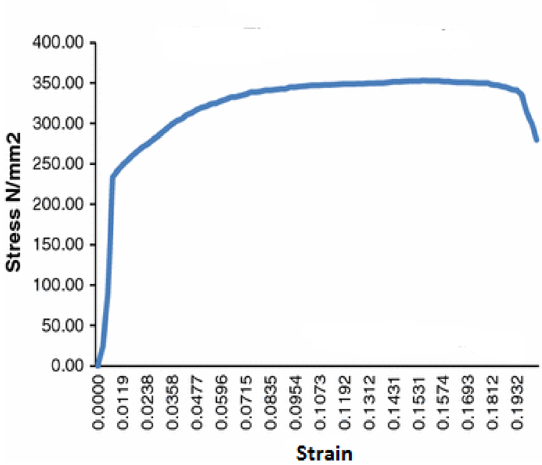

Figure 1: Stress vs. strain

EXPERIMENTAL INVESTIGATION

Test Specimens and End Connections

The specimens used in the present investigation were fabricated from Cold formed steel sheets of three different thicknesses 2,3 and 4 mm having different material properties. Tensile coupons were prepared and tested

Table 1: Tension Coupon Test Results

Thickness of steel sheet	2mm	3mm	4mm
Yield Stress in MPa **(f_y)**	220N/mm^2	232N/mm^2	244N/mm^2
Ultimate Stress in MPa **(fu)**	252N/mm^2	263N/mm^2	271N/mm^2
Modulus of Elasticity	2.03x10^5 N/mm^2	2.07x10^5 N/mm^2	2.11x10^5 N/mm^2
f_u/f_y	1.14	1.13	1.11
Percentage elongation	10 %	11 %	13 %

According to ASTM A 370 to determine the yield stress, ultimate stress and percentage elongation. Table 1 presents the average material properties obtained from the tension tests.

Figure 2: Single angles and Double angles

Bolted End Connection

The specimens were bolted to two hot-rolled ISAs of size varying connected to 8 mm thick gusset plate of size 150 × 280 mm. The angles which are bolted to the gusset plates were provided with a slot arrangement to accommodate specimens of different sizes and maintain the centre of gravity of specimens in line with the base plate. Bolt holes of 10 mm nominal diameter were made in the specimens to connect to the gusset angles confirming to AISI Manual - 1996.

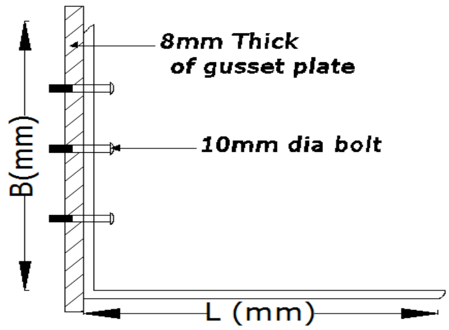

Figure 3: Single angle without Lip

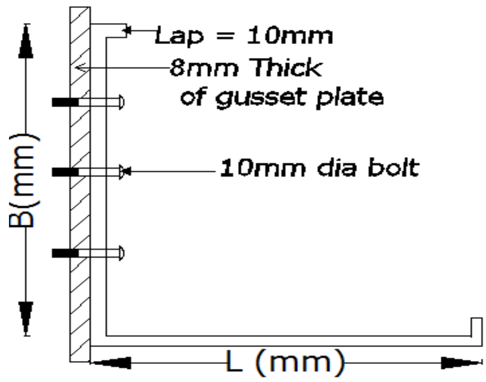

Figure 4: Single angle with Lip

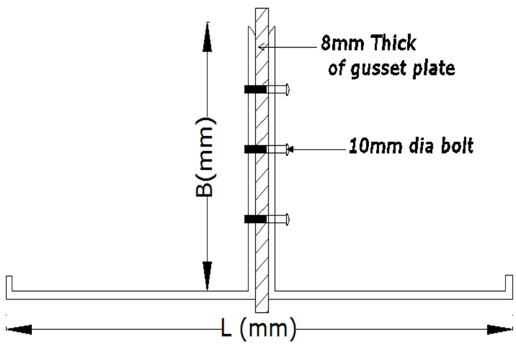

Figure 5: Double angle on same side without Lip

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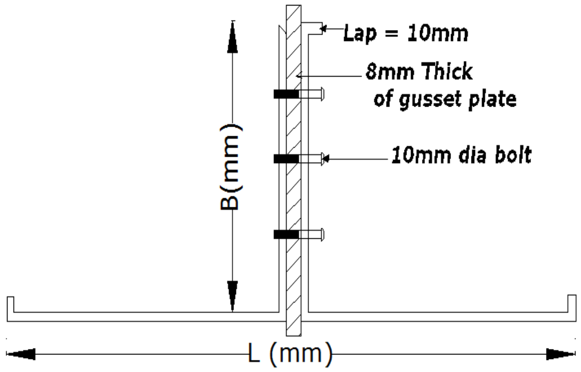


Figure 6: Double angle on same side with Lip

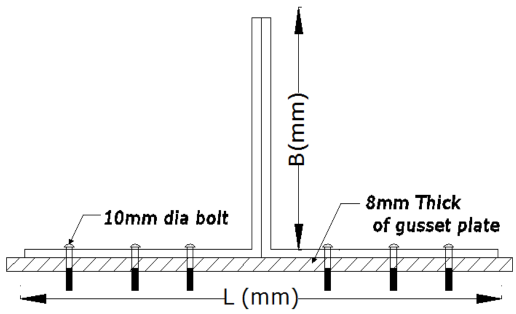


Figure 7: Double angle on opposite side without Lip

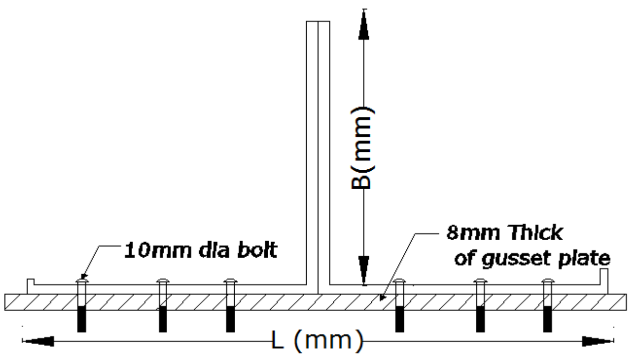


Figure 8: Double angle on opposite side with Lip

RESULT AND DISCUSSION

The test specimens are equal-leg steel angles made from S355 cold-formed steel, by using roll forming procedures. The specimens were supplied in different lengths without holes, thus each specimen was cut to specific lengths and drilled for the bolt connection. For the tension tests, 500-mm length was

used; while for the tension tests, the lengths 500 mm. Totally 108 specimens were used, i.e., 50x50,60x60,70x70,50x25, 60x30,70x35 mm and 2,3 and 4 mm nominal thickness for every cross section

Load Carrying Capacity

The experimental ultimate loads obtained for single angles, double angles welded back-to-back and starred angles and also their ratios are presented in Table 2.

Table 2. Ultimate Load-Carrying Capacity

S.No	Description	Size of Specimen	Design Strength ((P_{DS})		
			2mm	**3mm**	**4mm**
1	Single angle without Lip	50x50	31.10	46.59	56.84
		60x60	38.13	57.81	70.53
		70x70	45.26	68.00	82.96
		50x25	22.00	32.75	39.96
		60x30	25.70	40.67	49.62
		70x35	30.70	49.04	59.83
2	Single angle with Lip	50x50	37.32	54.66	66.69
		60x60	46.17	65.86	80.35
		70x70	54.37	72.43	88.36
		50x25	26.80	41.58	50.73
		60x30	31.34	49.57	60.48
		70x35	36.78	57.57	70.24
3	Double angle on opposite side without Lip	50x50	58.63	88.13	107.52
		60x60	72.11	108.40	132.25
		70x70	85.59	128.66	156.97
		50x25	41.78	66.10	80.64
		60x30	50.05	82.09	100.15
		70x35	59.79	98.08	119.66
4	Double angle on opposite side with Lip	50x50	71.02	104.34	127.29
		60x60	88.88	124.60	152.01
		70x70	103.37	144.86	176.73
		50x25	51.15	83.16	101.46
		60x30	60.59	99.15	120.96
		70x35	72.12	115.14	140.47
5	Double angle on same side without Lip	50x50	59.76	88.13	107.52
		60x60	73.70	108.40	132.25
		70x70	87.81	128.66	156.97
		50x25	41.98	66.10	80.64
		60x30	49.95	82.09	100.15
		70x35	59.85	98.08	119.66
6	Double angle on same side with Lip	50x50	72.37	104.34	127.29
		60x60	89.34	129.94	158.53
		70x70	106.35	151.07	184.31
		50x25	50.66	83.16	101.46
		60x30	60.77	104.48	127.47
		70x35	71.68	115.14	140.47

Load Vs Deflection

The typical load versus deflection has shown in Figure 9 to Figure 12 from the graphs, it is observed that the ultimate load carrying capacity increases as the cross-sectional area and number of bolts in the connection increases. It is also observed that when the rigidity of the connection increases the stiffness of the member also increases.

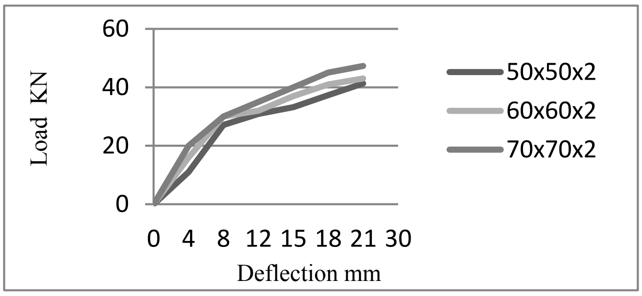


Figure 9: Double plain angle specimen opposite side

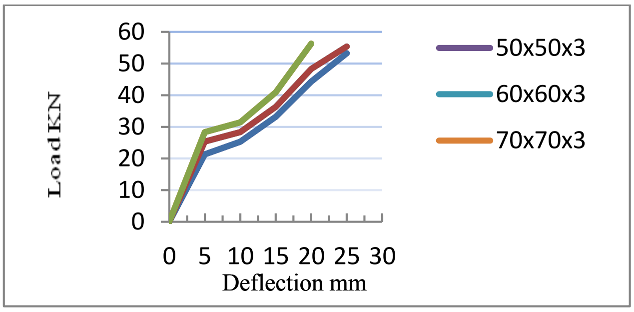


Figure 10: Single plain angle specimen without Lip 2mm

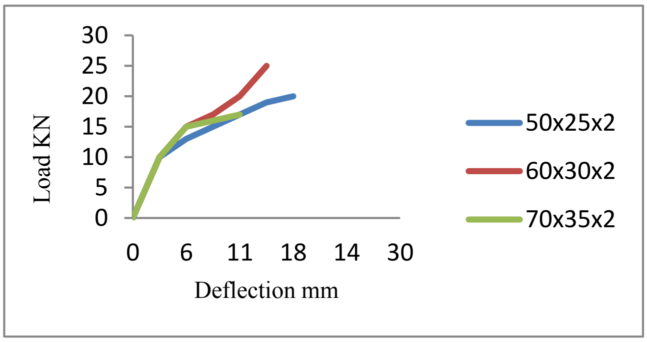


Figure 11: Double unequal angle specimen

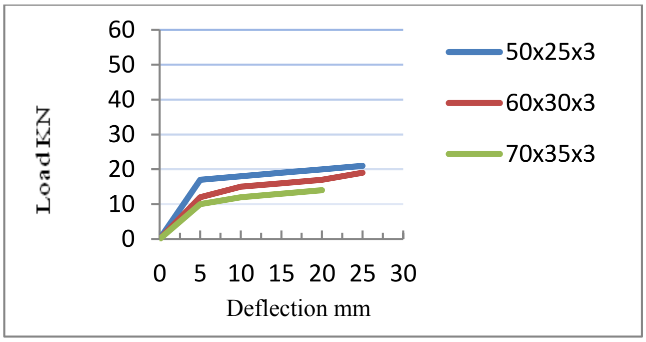


Figure 12: Double equal angle specimen

Modes of Failure

The modes of failure of all single and double angle specimens were noticed during testing. Generally tearing failure, block shear failure, net section fracture failure were observed as in Figure 13 to 16.Thus, a gap was formed between the corner of the connected leg and the gusset plate. This is referred as local bending. The mode of failure depends upon the cross section and rigidity of connection. The specimens carried some amount of load beyond the ultimate load and until failure. It was noted that all the bolts were still tight after completion of the tests. This indicates that the bolts were not highly stressed during the tests. The outstanding leg which is subjected to compression experiences, local buckling nearer to the supports. Mode of failure as shown in Table-3.

Table 3 : Mode of failure

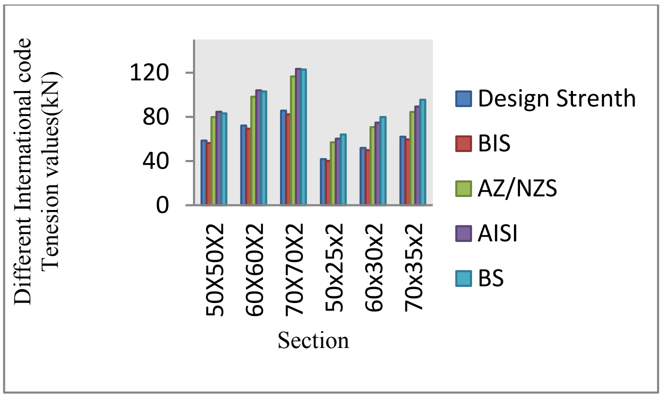
S.No	Specimens	Size / Mode of failure angles (2mm	Size / Mode of failure angles (3mm)	Size / Mode of failure angles (4mm)
1.	50x50	Net Section	Net Section	Block Shear
	60x60	Block Shear	Block Shear	Net Section
	70x70	Net Section	Net Section	Net Section
	50x25	Net Section	BlockShear	Net Section
	60x30	Block Shear	Block Shear	Block Shear
	70x35	Block Shear	Block Shear	Net Section

Design values from International codes

A comparative study between the experimentally observed ultimate loads of the specimen tested with the tensile load carrying capacity of equations of the following codes American Institute of steel corporation (AISI), AS/NZS:4600-2005, BS:5950 (Part 5)-1998 is made to review the procedures recommended. The comparison of predicted ultimate loads by the three various codes for single and double angles tested are shown in Table 4 and Figure 14 to Figure 17.

Table 4: Design values from International codes

\S.No	Description	Specimen	Size	Experimental Value (kN)(p_{exp})	BIS 800:2007	AS/NZS 4600: 2005	AISI 2007	BS:5950 (Part 5)-1998:
1	Single angle without Lip	Equal angles	50x50x2	31.10	28.19	33.94	42.28	39.03
			60x60x2	38.13	34.67	41.75	52.00	49.53
			70x70x2	45.26	41.15	49.55	61.72	58.00
		Unequal angles	50x25x2	22.00	20.09	24.19	30.13	31.23
			60x30x2	25.70	24.95	30.04	37.42	38.96
			70x35x2	30.70	29.81	35.89	44.71	46.68
2	Single angle with Lip	Equal angles	50x50x2	37.32	33.37	40.19	50.06	42.33
			60x60x2	46.17	39.85	47.99	59.78	52.05
			70x70x2	54.37	46.33	55.79	69.50	61.68
		Unequal angles	50x25x2	26.80	25.27	30.43	37.91	36.15
			60x30x2	31.34	30.13	36.28	45.20	44.11
			70x35x2	36.78	34.99	42.14	52.49	51.99
3	Double angle on opposite side without Lip	Equal angles	50x50x2	58.63	56.38	79.87	84.56	83.11
			60x60x2	72.11	69.34	98.23	104.00	102.99
			70x70x2	85.59	82.30	116.59	123.44	122.84
		Unequal angles	50x25x2	41.78	40.18	56.92	60.26	64.05
			60x30x2	50.05	49.90	70.69	74.84	79.78
			70x35x2	59.79	59.62	84.46	89.42	95.51
4	Double angle on opposite side with Lip	Equal angles	50x50x2	71.02	56.38	79.87	84.56	83.72
			60x60x2	88.88	69.34	98.23	104.00	103.57
			70x70x2	103.37	82.30	116.59	123.44	123.40
		Unequal angles	50x25x2	51.15	50.54	71.60	75.82	76.21
			60x30x2	60.59	60.26	85.37	90.40	92.31
			70x35x2	72.12	69.98	99.14	104.98	108.28
5	Double angle on same side without Lip	Equal angles	50x50x2	59.76	66.74	94.55	100.12	90.05
			60x60x2	73.70	79.70	112.91	119.56	112.78
			70x70x2	87.81	92.66	131.27	139.00	130.42
		Unequal angles	50x25x2	41.98	40.18	56.92	60.26	64.05
			60x30x2	49.95	49.90	70.69	74.84	79.78
			70x35x2	59.85	59.62	84.46	89.42	95.51
6	Double angle on same side with Lip	Equal angles	50x50x2	72.37	66.74	94.55	100.12	92.02
			60x60x2	89.34	79.70	112.91	119.56	112.78
			70x70x2	106.35	92.66	131.27	139.00	132.91
		Unequal angles	50x25x2	50.66	50.54	71.60	75.82	76.21
			60x30x2	60.77	63.50	89.96	95.26	96.02
			70x35x2	71.68	69.98	99.14	104.98	108.28



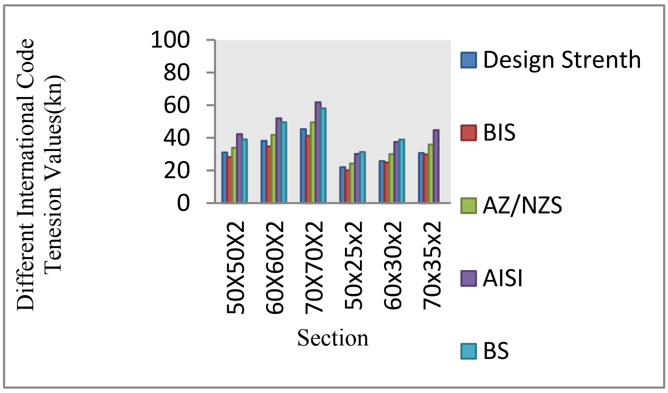


Figure 13: Comparison of Experimental results with various International codes

Figure 14: Longitudinal shear failure of 2 mm thick

Figure 15: Bearing + rupture failure

Figure 16: Block shear failure

Figure 1: **Tearing-Local Bucking**

CONCLUSIONS

All angles section values predicted by the international codes BIS,AISI, AS/NZS and BS . Experimental Ultimate loads are nearly 11% to 14% less all codal provisions .Comparisons were made between the test results and the predictions based on both the Experimental investigation and analysis. Results also comparisons were made by the International codes BIS, AISI, AS/NZS and BS. Based on the experimental, and analytical results were concluded. The experimental studies describes the load carrying capacity of single angles lipped section increases by 26% and double angles by 26% compare with plain angles of 2, 3 and 4mm section. The load carrying capacity of single angles lipped section increases by 28% and double angles by 32% in angle sections Results were recorded as the load carrying capacity increases for connected to the opposite side of the gusset than the connected to same side

SCOPE FOR FURTHER WORK

Similar experiments can be conducted on series of cold formed steel members with various thickness, to study the failure modes.

The above work can extended for different metal.

The work can be extended for specimen with punched hole instead of drilled hole as in present work

Behavior of these elements in trusses and structures can be studied.

The behavior of welded cold-formed angles may be studied in detail.

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