Design Strength and Structural Behaviour of Cold Formed Steel Plain Angle Members Subjected To Tension Load

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Abstract: **Cold formed steel is a basic components in construction of lightweight prefabricated structures like stud frame panels, trusses and prefabricated structures. Typically columns, beams and angles etc. are different globally. This research work deals with the details of an Experimental on cold-formed steel section subjected to tension load. This analysis carries single angle sections of 3mm and 4mm and double angles sections of 3mm and 4mm under plain (without Lipped) and with Lipped conditions subjected to tension. The papers present the load carrying capacity of single angles lipped section increases by 26% in 3mm and double angles by 29% in 3mm compare with plain angles in 4mm. Analyses were carried out for thirty six numbers of angle sections under condition such as Lipped were connected same side to gusset plate and connected to opposite side. Simultaneously, ultimate compressive strength of cold formed members has been investigated.**

Keywords: **Bucking behavior; Tension members; Cold-formed angles; Net section, Block Shear; Shear lag effect.**

I. INTRODUCTION

Cold formed steel products are made by bending a flat sheet of steel at room temperature; into a shape that will support more loads the flat sheet itself. Cold formed steel members are manufactures by cold rolling or press bracking and the plain angle sections are generally made by bending a plain sheet. Hence the original strip is converted into two distinct regions, corner portion and flat portion. Due to the cold forming, the mechanical properties of steel get modified. Generally there are four types of buckling such as local buckling, Flexural buckling, Torsional buckling and Distortional bucking. Global bucking is a bucking mode where the member deforms with no deformation in its cross sectional shape, consistent with classical beam theory. Local bucking is normally defined as the mode which plate-like deformations alone, without the translation of the intersecting lines of adjacent plate elements. Torsional buckling causes the element to twist parallel to the loading. Distortional bucking is a mode with cross- sectional that involves the translation the some of fold lines (intersection lines of adjacent plate elements).

II. REVIEW OF LITERATURE

Experiments on cold formed angle tension members were initiated by Holcomb et al.[1] at the University of Missouri-Rolla. They conducted 27 tests consisting of equal and unequal, angle thickness and connection eccentricity. [2] Schafer (2014) characterized geometric imperfections and residual stresses in the numerical analysis, found the moment capacity of laterally braced cold-formed steel flexural members with edge stiffened flanges which were affected by local or distortional buckling. They presented a new procedure for buckling stress in local and distortional mode. [3] Gotloru et al. (2013) studied the behavior of cold formed steel beams having open sections, which were subjected to torsion. They focused only on beams subjected to bending and torsion. They conducted a series of experimental study on angle sections and compared the result with simple geometric analysis, finite element analysis and finite strip analysis results.[4] Dubinq & Ungureanu(2014) made an analysis to study the influence of imperfections on the behavior of cold formed steel members. They paid special attention to the characterization and codification of imperfections for non-linear FEM simulation. [5] Young & Hancock (2012) experimentally investigated the cold formed steel channel section to combined bending and web crippling. A series of tests on unlipped channels rolled from high strength steel with thickness of 6mm and maximum web slenderness of 45 were conducted. The test results were discussed with the degree of accuracy with the Australian / New Zealand standards (AS\NZS 1996) and American Iron and steel Institute (AISI 1996) specifications and an interaction equation for strength prediction for combined bending and web crippling was presented.

This paper presents the effect of shear lag on the tensile capacities of cold formed angles. Practically angles are connected with gusset plates through one leg and due to this there will be non- uniform stress distribution due to Eccentrically applied load. The unconnected portion of a section is not fully effective in carrying the applied load.

Thus, the whole cross-section may not be fully utilized, which causes a reduction in the net section efficiency. Shear lag phenomenon is illustrated the unequal stress distribution, near to the connection region when subjected to tension. To simplify the design procedure of tension members, considerable amount of research has been carried out and some of their results are already incorporated in various international codes of practice. All the above investigations were made for the hot rolled double angle sections. There were only limited investigations for cold-formed steel members. The present investigation aims to study the behavior of cold-formed steel angle members.

III. EXPERIMENTAL INVESTIGATION

A totally thirty six experiments were conducted on single and double angle specimen of 3 mm and 4mm thickness which were connected to the gusset plate under eccentric tensile loads. The specimens were fabricated from 3mm and 4mm thickness cold- formed steel sheets of grade ST- 34-1079 by bending and press breaking operations. The tensile coupon test as per ASTM A370-03a specification shown in Fig 1, The reading were tabulated of yield stress, ultimate stress, modulus of elasticity and elongation obtained for these thicknesses of cold formed steel sheets as given in Table 1.

Table 1 Properties of Cold formes steel

Thickness of steel sheet	3mm	4mm
Yield Stress in MPa (**f**$_y$)	232N/mm^2	244N/mm^2
Ultimate Stress in MPa (**f**u)	263N/mm^2	271N/mm^2
Modulus of Elasticity	2.07x10^5 N/mm^2	2.11x10^5 N/mm^2
f_u/f_y	1.13	1.11
Percentage elongation	11 %	13 %

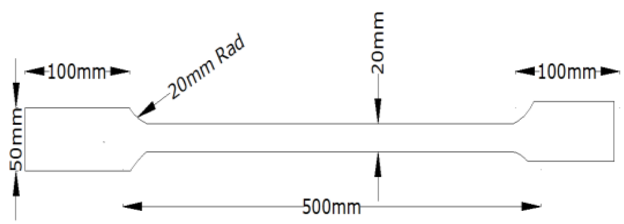
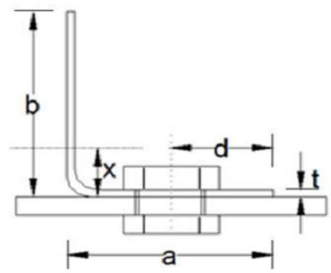


Fig.1 Tensile coupon test specimen



Shear lag width, bs = (b+a/2) - t

Fig. 2 Test – Setup

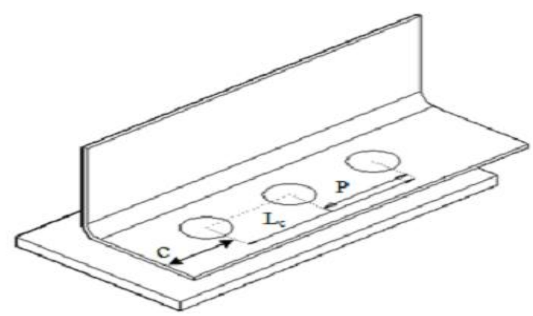


Fig.3 Dimension of Various parameters.

NO	Specimen I.d	Width of connected Leg a	Width of connected leg b	Thickness t	Bold Diameter b_d	End Distance c	Edge Distance d	Pitch Distance p	No of bolts	Connection length L_c	Connection eccentricity x	Shear lag distance b_s
		mm	mm	mm	mm	mm	Mm	mm	Nos.	mm	mm	mm
1	Single angle without Lip Equal Angles	50,60 &70	50,60 &70	3& 4	10	24	20	30	3	30	10.61	72.00
	Unequal Angles	50,60 &70	25,30 &35	3 &4	10	24	20	30	3	30	10.61	72.00
2	Single angle with Lip	50,60 &70	50,60 &70	3& 4	10	24	20	30	3	30	10.61	72.00

	Equal Angles Unequal Angles	50,60 &70	25,30 &35	3 &4	10	24	20	30	3	30	10.61	72.00
3	Double angle on opposite side without Lip Equal Angles	50,60 &70	25,30 &35	3& 4	10	24	20	30	3	30	10.61	72.00
	Unequal Angles	50,60 &70	25,30 &35	3 &4	10	24	20	30	3	30	10.61	72.00
4	Double angle on opposite side with Lip Equal Angles	50,60 &70	25,30 &35	3& 4	10	24	20	30	3	30	10.61	72.00
	Unequal Angles	50,60 &70	25,30 &35	3 &4	10	24	20	30	3	30	10.61	72.00
5	Double angle on opposite side with Lip Equal Angles	50,60 &70	25,30 &35	3& 4	10	24	20	30	3	30	10.61	72.00
	Unequal Angles	50,60 &70	25,30 &35	3 &4	10	24	20	30	3	30	10.61	72.00
6	Double angle on same side without Lip Equal Angles	50,60 &70	25,30 &35	3& 4	10	24	20	30	3	30	10.61	72.00
	Unequal Angles	50,60 &70	25,30 &35	3 &4	10	24	20	30	3	30	10.61	72.00

Table 2 Detail of test specimens

The specimens were tested as two different section configurations namely single angles and double angles. The single angle specimens were connected with their larger leg to end gusset plates of mild steel of 8mm thickness. Ordinary black bolts of 10mm diameter are used as connectors for specimens made from 3mm and 4mm. In case of specimens fabricated from 3mm and 4mm thickness sheet 10mm diameter bolts were used. The double angle specimens were connected with their larger leg with two mild steel gusset plates of 8mm using ordinary black bolts of 10mm diameter. The gusset plates were not reused for single angle specimens and were reused for double angle specimens. The required numbers of bolts are calculated for all specimens and were provided according to the design procedures. All the specimens were fabricated for a length of 500mm. The width of the gusset plate was kept 10mm more than the width of the connected leg. The length of gusset plate was provided according to the requirement of pitch and edge distance as per Indian code of practice. All the members were connected with gusset plate to the larger side by means of bolts.

The load is gradually applied with suitable increments from control panel and at each increment of loads corresponding elongation was taken. The yield, ultimate and breaking loads were also observed. The distance of separation between gusset plate and test specimens was also recorded. The procedure is repeated till the failure stage is reached in all specimens. The observed yield load and ultimate load of the specimens tested are recorded.

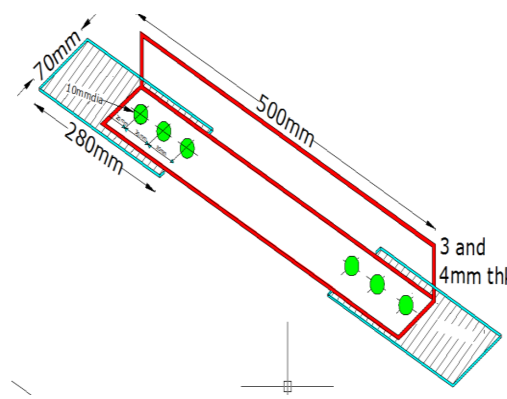


Fig.4 Single angle without Lip

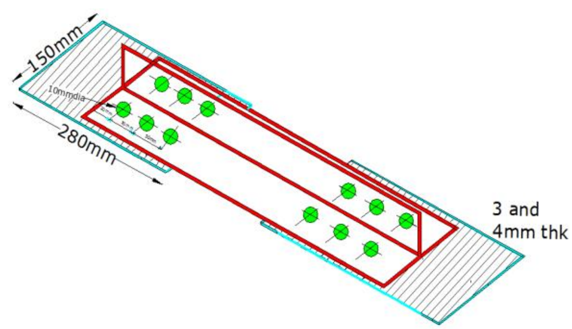
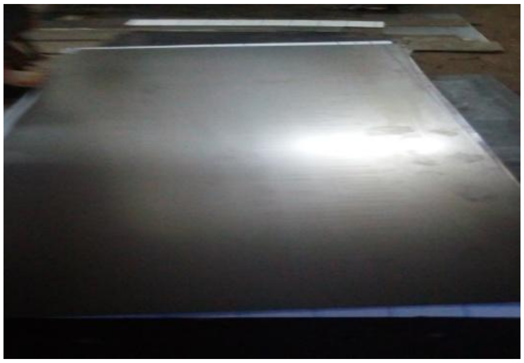


Fig.6 Double angle on same side without Lip



\ Fig.8 Cold formed steel sheet

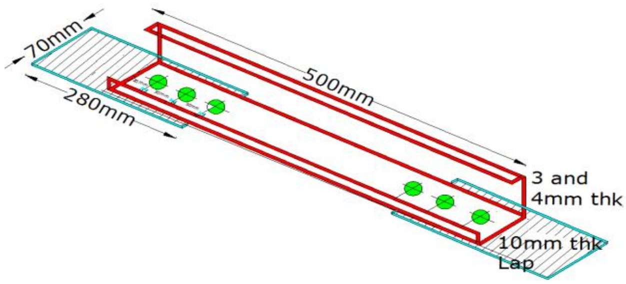


Fig.5 Single angle with Lip

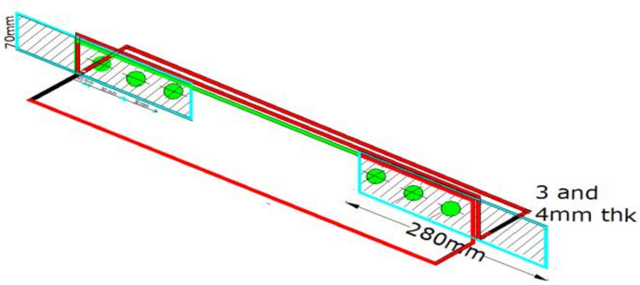


Fig.7 Double angle on opposite side without Lip

Fig.9 Angles fixed in universal testing machine (UTM)

IV. RESULT AND DISCUSSION

Ultimate Load-Carrying Capacity

A total of thirty six specimens have been tested by varying the angle sizes, number of bolts and the bolt pitch distance. All the specimens have been designed to undergo net section rupture failure. The specimens are equal angles of dimensions 50x50mm, 60x60mm and 70x70 mm and they have equal length 500mm and thickness 3 mm and 4mm and unequal angle of 50x25mm, 60x30mm and 70x35 mm and they have equal length 500mm and thickness 3 and 4 mm respectively. The experimental ultimate loads for all the cold-formed steel single angles are presented in Table 3. It is observed that comparison of 3mm and 4mm thickness, single equal lipped angles the average increase in ultimate load is 1.22 times greater than that of single equal plain angles. From this research observed that when the cross-sectional area increases, the load carrying capacity increases.

S.No	Description	Size of Specimen	Ultimate Load (P_{Ul}) kN		Yield Load (P_{yl}) kN		Design Strength ((P_{DS})	
			3mm	4mm	3mm	4mm	3mm	4mm
1	Single angle without Lip	50x50x3	96.28	115.54	77.64	93.94	46.59	56.84
		60x60x2	119.48	143.38	96.35	116.58	57.81	70.53
		70x70x2	140.54	168.65	113.34	137.14	68.00	82.96
		50x25x2	67.68	81.22	54.58	66.04	32.75	39.96
		60x30x2	84.06	100.87	67.79	82.03	40.67	49.62
		70x35x2	101.35	121.62	81.73	98.89	49.04	59.83
2	Single angle with Lip	50x50x2	112.96	135.55	91.09	110.22	54.66	66.69
		60x60x2	136.11	163.33	109.77	132.82	65.86	80.35
		70x70x2	149.69	179.63	120.72	146.07	72.43	88.36
		50x25x2	85.93	103.12	69.30	83.85	41.58	50.73
		60x30x2	102.45	122.94	82.62	99.97	49.57	60.48
		70x35x2	118.98	142.78	95.95	116.10	57.57	70.24

3	Double angle on opposite side without Lip	50x50x2	182.14	218.57	146.89	177.74	88.13	107.52
		60x60x2	224.02	268.82	180.66	218.60	108.40	132.25
		70x70x2	265.89	319.07	214.43	259.46	128.66	156.97
		50x25x2	136.60	163.92	110.16	133.29	66.10	80.64
		60x30x2	169.65	203.58	136.82	165.55	82.09	100.15
		70x35x2	202.70	243.24	163.47	197.80	98.08	119.66
4	Double angle on opposite side with Lip	50x50x2	215.64	258.77	173.91	210.43	104.34	127.29
		60x60x2	257.51	309.01	207.67	251.28	124.60	152.01
		70x70x2	299.39	359.27	241.44	292.14	144.86	176.73
		50x25x2	171.86	206.23	138.59	167.69	83.16	101.46
		60x30x2	204.91	245.89	165.25	199.95	99.15	120.96
		70x35x2	237.95	285.54	191.90	232.20	115.14	140.47
5	Double angle on same side without Lip	50x50x2	182.14	218.57	146.89	177.74	88.13	107.52
		60x60x2	224.02	268.82	180.66	218.60	108.40	132.25
		70x70x2	265.89	319.07	214.43	259.46	128.66	156.97
		50x25x2	136.60	163.92	110.16	133.29	66.10	80.64
		60x30x2	169.65	203.58	136.82	165.55	82.09	100.15
		70x35x2	202.70	243.24	163.47	197.80	98.08	119.66
6	Double angle on same side with Lip	50x50x2	215.64	258.77	173.91	210.43	104.34	127.29
		60x60x2	268.55	322.26	216.57	262.05	129.94	158.53
		70x70x2	312.22	374.66	251.79	304.67	151.07	184.31
		50x25x2	171.86	206.23	138.59	167.69	83.16	101.46
		60x30x2	215.92	259.10	174.13	210.70	104.48	127.47
		70x35x2	237.95	285.54	191.90	232.20	115.14	140.47

Table 3 Ultimate Load-Carrying Capacity

Load vs Deflection

The typical load versus deflection has shown in Fig 10 to Fig 15 to shows the behavior for single angles with and without lips and double angles. 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.

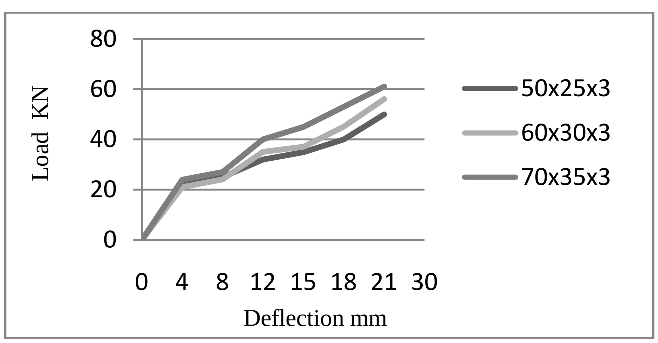


Fig.10 Load vs Deflection behavior of single plain angle specimen – without Lip (3mm)

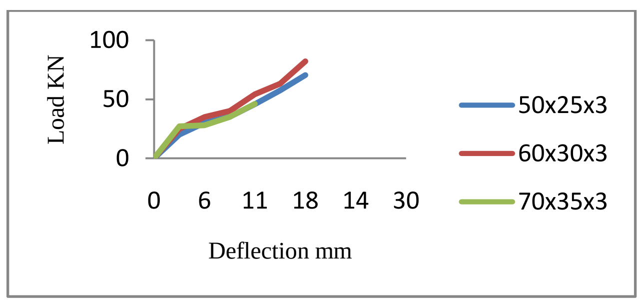


Fig.11 Load vs Deflection behavior of Double angle opposite side specimen - without Lip (3mm)

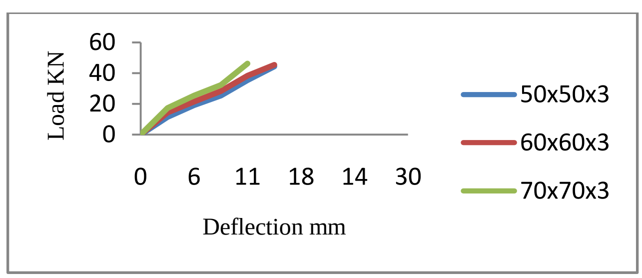


Fig.12 Load vs Deflection behavior of unequal single plain angle specimen - without Lip (4mm)

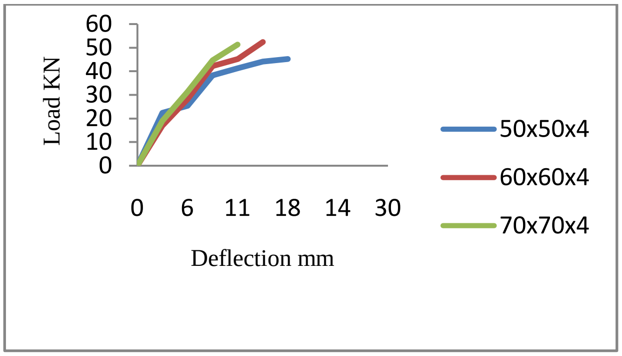


Fig.13 Load vs Deflection behavior of single unequal angle specimen – with lip

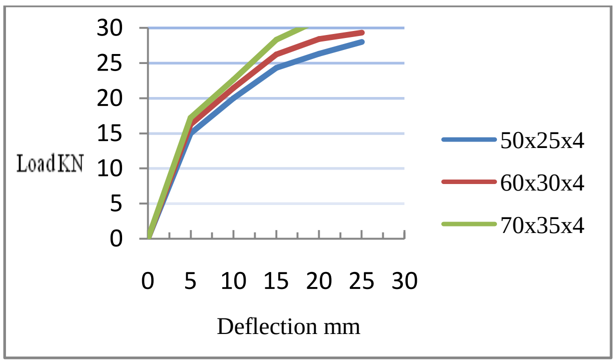


Fig.14 Load vs Deflection behavior of unequal single plain angle specimen - with lip(4mm)

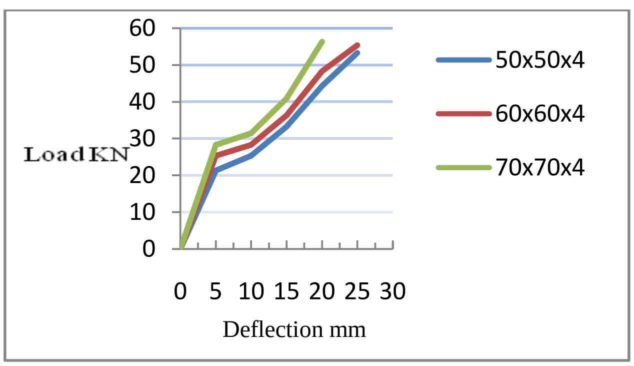


Fig.15 Load vs Deflection behavior of unequal double angle specimen - with lip

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 Figure16 and 17.As the load was being applied, the corners of the angle at the two ends gradually separated from the gusset plates for both single and double angle members. 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. Finally, the plate tears along a horizontal line that is coincident with the widest point of the bolt hole in tearing failure. The design strength of tension members are not always controlled by factor of safety or by the strength of the bolts or welds with which they are connected. After necking, the critical cross-section was torn out from the edge of the connected leg to the hole then to the corner of the angle. 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.

Fig.16 Single Plain angle without Lip (3mm)

Fig.17 Double angle without Lip (4mm)

S.No	Specimens	**Size / Mode of failure angles (3mm)**	**Size / Mode of failure angles (4mm)**	**Size / Mode of failure angles (3mm)**	**Size / Mode of failure angles (4mm)**
		Single angle without Lip		**Single angle with Lip**	
1	**Equal angles**	50x50x3 - Net Section	50x50x4-Net Section	50x50x3-Net Section	50x50x4-Net Section
		60x60x3- Block Shear	60x60x4-Block Shear	60x60x3-Block Shear	60x60x4-Block Shear
		70x70x3 - Net Section	70x70x4- Net Section	70x70x3-Net Section	70x70x4-Net Section
	Unequal Angles	50x25x3- BlockShear	50x25x4 Block Shear	50x25x3Block Shear	50x25x4 Block Shear
		60x30x3 Block Shear	60x30x4 Block Shear	60x30x3- Block Shear	60x30x4 Block Shear
		70x35x3- Block Shear	70x35x4-Block Shear	70x35x3 - Block Shear	70x35x4-Block Shear
2		**Double angle on opposite side without Lip**		**Double angle on opposite side with Lip**	
	Equal angles	50x50x3 - Net Section	50x50x4- Net Section	50x50x3-Net Section	50x50x4- Net Section
		60x60x3- Block Shear	60x60x4-Block Shear	60x60x3-Block Shear	60x60x4-Block Shear
		70x70x3 - Net section	70x70x4- Net Section	70x70x3- Net Section	70x70x4- Net Section
	Unequal Angles	50x25x3- BlockShear	50x25x4- Block Shear	50x25x3 Block Shear	50x25x4 Block Shear
		60x30x3- Block Shear	60x30x4- Block Shear	60x30x3 Block Shear	60x30x4 Block Shear
		70x35x3 - BlockShear	70x35x4-Block Shear	70x35x3-Block Shear	70x35x4-Block Shear
3		**Double angle on same side without Lip**		**Double angle on same side with Lip**	
	Equal angles	50x50x3 - Net Section	50x50x4- Net Section	50x50x3-Net Section	50x50x4- Net Section
		60x60x3- Block Shear	60x60x4-Block Shear	60x60x3-Block Shear	60x60x4-Block Shear
		70x70x3 - Net Section	70x70x4- Net Section	70x70x3- Net Section	70x70x4- Net Section
	Unequal Angles	50x25x3 Block Shear	50x25x4 Block Shear	50x25x3 Block Shear	50x25x4 Block Shear
		60x30x3 Block Shear	60x30x4 Block Shear	60x30x3 Block Shear	60x30x4 Block Shear
		70x35x3 - Block Shear	70x35x4-Block Shear	70x35x3-Block Shear	70x35x4-Block Shear

Table 4. Mode of failure

V. CONCLUSIONS

Based on the experimental, and analytical results were concluded.

1. The load carrying capacity of single angles lipped section increases by 26% in 3mm and double angles by 29% in 3mm compare with plain angles in 4mm.
2. Results were recorded as the load carrying capacity increases for connected to the opposite side of the gusset than the connected to same side.

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