Mode of Failures on Cold Formed Steel Angle Sections Under Tensile Load

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Abstract- *Tension members consisting of single and double angles, single channels and similar sections are frequently used for lateral bracing and as truss elements. Such members normally have eccentric connections which results in bending of tension member. It is often permitted, by current design specifications, to neglect this eccentricity in the design of the member. The present study is focus on mode of failure on cold formed steel angle. This analysis carries single angles and double angles sections of 2mm under plain (without Lipped) and with Lipped conditions subjected to tension. Analyses were carried out for thirty-six numbers of angle sections under condition such as double angle were connected same side to gusset plate and connected to opposite side. Figure shows connection failure and mode of failure. Local buckling, global buckling, tearing failure, net section failure, and block shear failure.*

Keywords- Mode of failure, connection failure, cold formed steel, Net section Efficiency, Ultimate strength

I. INTRODUCTION

The design of commercial building is ruled primarily by useful necessities and therefore the want for economy of construction. In cross-sections, these buildings can vary from single or multi bay structures of larger span. Once supposed to be used as warehouses or craft hangers to smaller span buildings for factories, assembly plants, maintenance facilities, packing plants etc.The most dimensions can nearly invariably be settled by the actual operational activities concerned, however the structural designer's input on optimum spans and therefore the choice of appropriate cross-sections profile will have a crucial pertaining to achieving overall economy.

II. COLD FORMED STEEL

It increases the design flexibility and allows very attractive, economical, and sustainable solutions. The factor of safety for angles under tension in the limit state format giving due considerations to blocks bearing failure and yielding of gross section was obtained. The knowledge and understanding of the behavior of cold formed steel bolted connections, to determine tensile capacity, bearing capacity and the interaction of tension and bearing capacities were performed.

III. NET SECTION EFFICIENCY

The net section efficiency 'U' of the member was calculated based on the ultimate load and the measured ultimate strength of material in tension coupon test (fu).

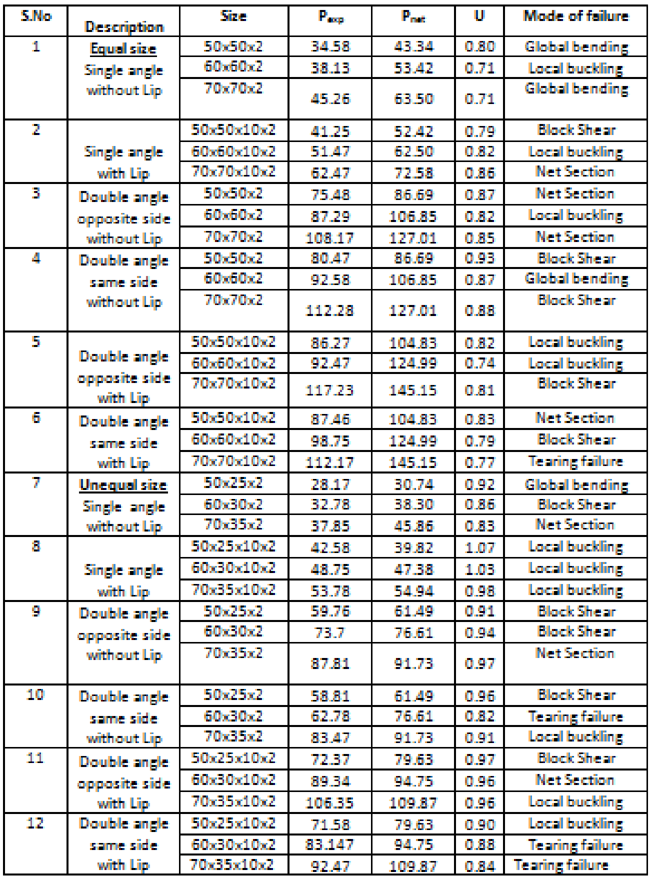
$U = P_{exp} / P_{net}$,
$P_{net} = f_u * A_n$, where
U = Net section efficiency
f_u= Ultimate strength of the material
A_n = Net area of the cross section

The experimental research results are presented and discussed. Tests conducted in cold formed steel angles are presented, connected by bolts, and submitted to tensile loads. When the bolted connection is considered, the angle does not deform evenly, showing the phenomenon known as shear lags. The steel angle collapse of the net section is examined for the calculation of the ultimate capacity of the tension members and the shear lag phenomenon is considered by the U factor. This coefficient reduces the net section and reduces the resistant capacity of the tensioned steel angle.

The tension member's efficiency is defined as the ratio of the members, design tensile capacity to normal or available tensile strength. Depending on the member section configuration and the type of end connection, the efficiency ranged from 0.70 to 1.10. In the case of single unequal angles with a lip connected to the gusset plate by bolted connection, the highest efficiency valve is obtained and the lower valve is generally obtained in the bolted single equal angels.

To increase the efficiency of the outstanding angle in single angles and to reduce the length of the end connections, a short length of an angle section was sometimes used in the joint to connect the outstanding leg of the angle sections to the gusset plate. These angles are called Lug angles. Cold steel structural members can lead to more economic design than hot rolled members due to their high weight ratio, easily manufactured and built. Moreover, the significant advantages of cold-formed sections are increased yield strength, post-buckling strength and suitable for a wide range of applications. These sections are primarily thin walled with moderate to terribly high flat widths or elements.

Table 1 Net section Efficiency of angle section thickness of 2mm



S.No	Description	Size	P_{exp}	P_{net}	U	Mode of failure
1	Equal size Single angle without Lip	50x50x2	34.58	43.34	0.80	Global bending
		60x60x2	38.13	53.42	0.71	Local buckling
		70x70x2	45.26	63.50	0.71	Global bending
2	Single angle with Lip	50x50x10x2	41.25	52.42	0.79	Block Shear
		60x60x10x2	51.47	62.50	0.82	Local buckling
		70x70x10x2	62.47	72.58	0.86	Net Section
3	Double angle opposite side without Lip	50x50x2	75.48	86.69	0.87	Net Section
		60x60x2	87.29	106.85	0.82	Local buckling
		70x70x2	108.17	127.01	0.85	Net Section
4	Double angle same side without Lip	50x50x2	80.47	86.69	0.93	Block Shear
		60x60x2	92.58	106.85	0.87	Global bending
		70x70x2	112.28	127.01	0.88	Block Shear
5	Double angle opposite side with Lip	50x50x10x2	86.27	104.83	0.82	Local buckling
		60x60x10x2	92.47	124.99	0.74	Local buckling
		70x70x10x2	117.23	145.15	0.81	Block Shear
6	Double angle same side with Lip	50x50x10x2	87.46	104.83	0.83	Net Section
		60x60x10x2	98.75	124.99	0.79	Block Shear
		70x70x10x2	112.17	145.15	0.77	Tearing failure
7	Unequal size Single angle without Lip	50x25x2	28.17	30.74	0.92	Global bending
		60x30x2	32.78	38.30	0.86	Block Shear
		70x35x2	37.85	45.86	0.83	Net Section
8	Single angle with Lip	50x25x10x2	42.58	39.82	1.07	Local buckling
		60x30x10x2	48.75	47.38	1.03	Local buckling
		70x35x10x2	53.78	54.94	0.98	Local buckling
9	Double angle opposite side without Lip	50x25x2	59.76	61.49	0.91	Block Shear
		60x30x2	73.7	76.61	0.94	Block Shear
		70x35x2	87.81	91.73	0.97	Net Section
10	Double angle same side without Lip	50x25x2	58.81	61.49	0.96	Block Shear
		60x30x2	62.78	76.61	0.82	Tearing failure
		70x35x2	83.47	91.73	0.91	Local buckling
11	Double angle opposite side with Lip	50x25x10x2	72.37	79.63	0.97	Block Shear
		60x30x10x2	89.34	94.75	0.96	Net Section
		70x35x10x2	106.35	109.87	0.96	Local buckling
12	Double angle same side with Lip	50x25x10x2	71.58	79.63	0.90	Local buckling
		60x30x10x2	83.147	94.75	0.88	Tearing failure
		70x35x10x2	92.47	109.87	0.84	Tearing failure

IV. MODES OF FAILURE

A tension member was loaded until strain hardening is reached and elongates excessively before the fracture causing the members to fail at the angle. The failure modes for single and double- angle specimens were observed during the test. Generally, different types of failure modes were used for single and double angle sections, namely global bending, local bending, local buckling, tearing failure, shear failure, net fracture. The failure mode depends on the cross- sectional area and the connection stiffness. In the current work, failure modes have been studied in the single- angle and double-angle sections.

The initiation of a particular failure mode is observed to depend on the geometric characteristics, material properties, and loading conditions of the angle sections. The angle sections of the gusset plate remained straight during the loading process. The gusset plate of the angle sections was bent during tensile loading conditions in the case of single angles. The angle sections of the moulding plate remained straight during the loading process. The gusset plate of the angle sections was bent during tensile loading conditions in the case of single angles. This bending type is referred to as global bending. Fig 1 shows the global bending of specimens of single plain angle.

Fig 1 Failure due to global bending of single plain angle specimen

The load of tension was applied in the members, the corners of the angles gradually separated from the gusset plates at the two ends for both single and double angles. The gap between the corner of the connected leg and the gusset plate was then formed. This type of bending is referred to as local bending. Larger gaps typically have been linked to higher cross- sectional eccentricity, smaller angle thicknesses, and shorter connection lengths. Fig 2 to 3 show the local bending of the Lip specimen of single angles. The visible gap length was usually from the edge of the angle to the inner bolt. The width of gap from one specimen to another, the valve is 12mm was observed in the angle sections.

Fig 2 Failure due to local bending of single angle with Lip

Fig 3 Failure due to local bending

In the case of single angles tested in the bolted connection, local buckling was observed. The local buckling occurred in the middle of the flange or between the mid height and one third of the angle section. The specimens carried a certain load beyond the ultimate load until failed. It was observed that all the bolts were still close after the tests were completed. During tests, the bolts were not highly stressed. The outstanding leg that is compressed experiences a local buckling closer to the supports. Fig 4 shows failures due to local buckling of single angle specimens.

Fig 4 Failures due to local buckling of single angle specimen 70x70x2

V. CONNECTION FAILURE

Connect failures are not so ductile as angle failures. There are three general failure categories that occurred during testing. Failure to tear, failure of the shear block and failure of the Net section.

Tearing failure

This type of failure occurred in most of the bolts inside as the ultimate load was achieved. The minimum edge distance in the angles is provided, and the yielding is initiated at the innermost bolthole. If the bolts are stronger than the plates, a tearing failure occurred. The tension failure of a bolt is shown in Fig.5

Fig 5 Failures due to tearing in bolts of single angle specimen 70x70x2

Block shear failure

This type of failure occurs at a faster rate compared to tearing failure. Segments of blocks of material at end of member shear out due to the possible use of high strength bolts resulting in smaller connection length. Yielding of two innermost boltholes, the net section area reduces considerably, which reduces in bock shear failure. Fig 7 to 10 shows the block shear failure of all angle specimens. Limit state of block shear are combined shear and tension failure.

Fig 7 Failures due to block shear of single equal angle specimen 50x50x2

Fig 8 Failures due to block shear of single equal angle specimen 50x50x2

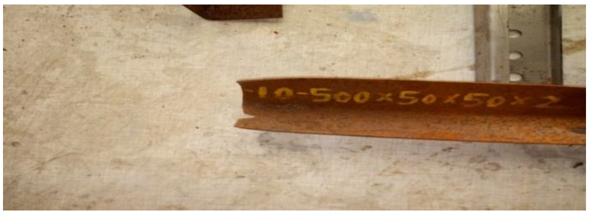


Fig 9 Failures due to block shear of single unequal angle specimen 50x50x2

Fig 10 Failures due to block shear of single equal angle specimen with Lip 70x70x2

Net section fracture failure

Fig 11 to 12 shows the net section, failure of angle sections specimens. The rupture of the member when the net cross section of the member reaches the ultimate stress. If the material is ductile, local yielding at the edge of the hole due to stress concentration allows for a redistribution of stress in the net section. The failure occurs at the innermost bolt hole and the crack towards it.It is also observed that when the connected leg fails due to net section fracture, the outstanding leg under compressive stress suffers local buckling.

Fig 11 Failures due to net section of single un equal angle specimen 70x35x2

Fig 12 Failures due to net section of single angle specimen 50x50x2

VI. CONCLUSION

The study focused on mode of failure in cold formed angle section under tensile loading. Here the connection length is increased by increasing the pitch between the holes instead of increasing the number of bolts .In all of the specimens, failure is caused due to the partial net section rupture of the connected leg adjacent to the lead bolt hole. The analysis indicated an excellent agreement with the experimental failure capacities of the specimens with large connection eccentricities. In addition, these models are able to accurately capture the partial net section rupture failure mode observed in the experimental specimens.

VII. SCOPE FOR FUTURE WORK

- The above work can be extended for different thickness
- The work can be extended for specimen with the punched hole instead of drilled hole as in present work.
- Higher order element can be used to get results that are more precise.

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