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EXPERIMENTAL INVESTIGATION OF BOLTED COLD FORMED STEEL ANGLE UNDER TENSION

Sonal Banchhor*, M.K. Gupta
* Assistant Professor, Civil Department, Bhilai Institute of Technology, Durg, INDIA
HOD , Civil Department, Bhilai Institute of Technology, Durg, INDIA

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ABSTRACT

Tension members are used in a variety of structures such as trusses, transmission towers etc. The most widely used structural shapes are the angle sections and the channel sections. Angle may use as single angle or double angles and the connection may be bolted or welded. Most of the design provisions for hot- rolled tension members are available and only few studies were reported in literature regarding behavior of cold formed steel bolted angle tension members.The main objective of this study is to investigate the behavior of cold steel single and double angle subjected to tension. Experimental, theoretical investigations were carried out for single angle, double angle connected to opposite sides of gusset plates and double angle connected to same side of gusset plates.

KEYWORDS: Cold steel, Tension, Stress, UTM.

INTRODUCTION

1.1 STRUCTURE

Structure is a free-standing, immobile outdoor construction. Typical examples includes building and non-building structure ones such as bridges and dams. Some structures are temporary, built for some events such as trade shows, conferences or theatre, and often dismantled after use. Temporary structures have fewer constraints relating to future use and durability. Some structures are permanent.

1.2 TRUSSES

Truss is a structure, comprising one or more triangular units constructed with straight members whose ends are connected at joints referred to the nodes. External forces and reactions to those forces are considered to at only at the nodes and results in forces in the members which are either tensile or compressive force.

A planar truss is one where all the members and nodes lie within a two dimensional plane, while a space truss has members and nodes extending into three dimensions.

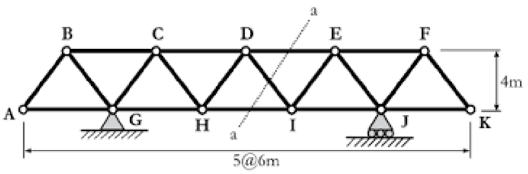

Figure 1.1. Planar Truss

Figure1.2. Space Truss

1.3 STRUCTURAL MEMBERS

Structural steel members are extensively used in structures such as bridges, roof trusses, transmission line towers, multistoried buildings etc., because of its high strength to weight ratio, resulting in the reduction of dead weight.

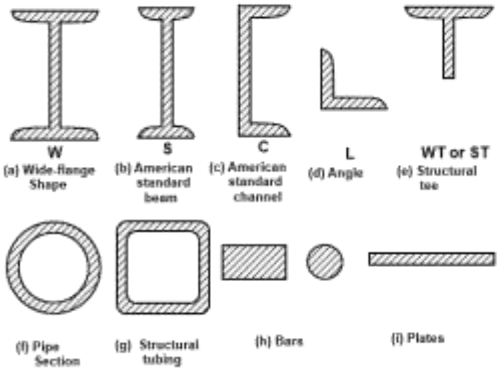

Figure 1.3. Classifications of structural member based on its shape

The two main groups of structural steel members are hot-rolled steel members and cold-formed steel members.

In recent years, cold-formed steel sections have gained considerable prominence over hot-rolled sections. Two main reasons attributed to the above fact are, their economy achieved for relatively light load under moderate spans and their sectional configurations, which provides a choice for the architects and designers.

CODAL PROVISIONS

2.1 GENERAL

The aim of structural design is to ensure that a structure fulfills its intended purpose during its lifetime with adequate safety and serviceability performance. Increase in utilization of cold-formed steel members has been largely due to the sustained research. Considerable improvement in the knowledge gained through research in the intervening time has led to batter design guidelines as reflected in literature and many resent international codes of practice. Compression of the provision of the British, American, Australian and New Zealand standard is carried out along with experimental result.

Allowable Stress Design (ASD) or the limit state approach usually referred as Load and Resistance Factor Design (LRFD) are the basis for the determination of load carrying capacities of cold-formed steel members.

Most of the specification AISI, AS/NZS, and BS have switched over from ASD to LRFD. AISI standard allows the use of both the ASD and LRFD, whereas IS follows the Allowable Stress Design approach.

2.1.1 Allowable Stress Design

Allowable Stress Design also known as the elastic design is based on the elastic limit of the material. The elastic limit is nothing but the maximum stress, which a material can withstand without being permanently deformed. The allowable stress is obtained by dividing either the yield stress or the ultimate tensile strength by a factor of safety. The factor of safety is the ratio of yield point of the material to its working stress. In ASD it is ensured that "the stresses in a structure under working or service loads do not exceed designated allowable values".

The general format of the Allowable Stress Design is

$$R_n / FS \geq \sum_{i=1}^{m} Q_{ni} \tag{1}$$

Where R_n = Nominal resistance of the structural member
Q_n = Nominal working or service stress compound under working loads
FS = Factor of safety
i = type of load
m = number of load types

The term R_n / FS represents the allowable stress of the structural member or component under a given loading condition. The term Q_n represents the combined stresses produced by various load conditions. In this method the factor of safety is applied only to the resistance term and safety is evaluated in the load term. Therefore allowable stress design is characterized by the use of unfactored 'working loads' in conjunction with a single factor of safety applied to the resistance. Because of the greater variability and unpredictability of the live load and other loads in comparison with the dead load, a uniform reliability is not possible with Allowable Stress Design.

2.1.2 Limit State Design

Limit state means "those condition of a structure at which it ceases to fulfill its intended function". It is divided into two category as strength and serviceability.

- The strength Limit State deals with behavioural phenomenon such as achieving ductile maximum strength, buckling, fatigue and fracture, overturning and sliding.
- The serviceability Limit state are those concerned with occupancy of the building such as deflection, vibration, permanent deformation and cracking.

The ultimate limit state is checked for strength consideration and the serviceability limit state is checked for actual service condition. The load acting and the resistance of the structure to load are variable that are considered in the Limit state Design.

For a safe structure it is required that

$$Q<R \tag{2}$$

where Q = load and R = resistance

The general format for Limit State Design is

$$\phi R_n \geq \sum_{i=1}^{m} \gamma_i Q_{ni} \tag{3}$$

where R_n = nominal strength
φ = resistance factor
γ_i = load factor
Q_n = load effects

The term φ R_n represents the resistance or strength of the component. The term γ_i Q_{ni} represent the load expected. Normally γ is larger than unity and φ is less than unity.

2.1.3 Importance of Limit State Design

Ductile structural materials such as steel can withstand strain much larger than those encountered with in the elastic limit. Design methods, which are based on elastic limit, fail to take advantage of the ability of such material to carry stress above the yield stresses (strain hardening). The ductile material will cause redistribution of stresses beyond the elastic limit. These redistribution of stresses carry often additional loads. From this view point elastic analysis is unduly conservative. The limit state design method offers alternative to the objections in the elastic design. It takes full advantage of ductility and the method is mathematically simple.

EXPERIMENTAL INVESTIGATION

The specimens used in the present investigation were fabricated from steel sheets of three different thicknesses 2, 3 and 4 mm by bending and press breaking operations. Standard tension tested on each thickness of steel were conducted to study the mechanical properties of the steel sheets used to prepare the specimens. The tension tests coupons were prepared for 2mm ,3mm and 4mm thick sheet tested according to IS 1079-1994 specifications. Figure 3.1 shown the details of tension coupon specimen.

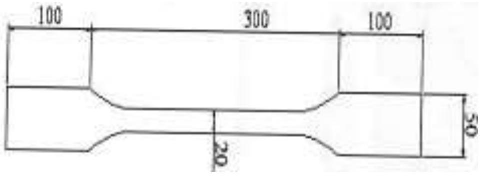

Figure 3.1 Tensile Test Specimens for Material of Metal Sheet

Table 1: Mechanical Properties of Material of 2mm thick sheet

Thickness of Tensile test specimen = 2 mm
Gauge length = 50 mm
Width at gauge length = 20 mm
Cross section area of test specimen = 40 sq.mm.
Gauge length after fracture = 62 mm
Maximum load before breaking = 1200 kgf
= 11.772 kN
Ultimate tensile strength = 294.3 MPa
Percentage Elongation = 24 %

Table 2: Mechanical Properties of Material of 3mm thick sheet

Thickness of Tensile test specimen = 3 mm
Gauge length = 50 mm
Width at gauge length = 20 mm
Cross section area of test specimen = 60 sq.mm.
Gauge length after fracture = 61 mm
Maximum load before breaking = 1600 kgf
= 15.696 kN
Ultimate tensile strength = 261.6 MPa
Percentage Elongation = 22 %

Table 3: Mechanical Properties of Material of 4 mm thick sheet

Thickness of Tensile test specimen = 4 mm
Gauge length = 50 mm
Width at gauge length = 20 mm
Cross section area of test specimen = 80 sq.mm.
Gauge length after fracture = 60 mm
Maximum load before breaking = 2200 kgf

= 21.582 kN
Ultimate tensile strength = 269.8 MPa
Percentage Elongation = 20 %

Table 4: Mechanical Properties of Material of Steel Sheet

Thickness of Steel Sheet (in mm)	**Ultimate Tensile Stress (in MPa)**	**Percentage Elongation (in Percentage)**
2	294.3	24
3	261.6	22
4	269.8	20

3.1 EXPERIMENTAL PROGRAMME

In the present investigation nine specimens were tested to study the behaviour of cold-formed steel single angles, and double angles. A series of tension test were conducted on specimens and their behaviour is observed in the elastic as well as in the plastic ranges of loading. Specimens were fabricated from cold-formed steel sheets of thickness 2, 3, and 4mm. the cold-formed steel sheets were bent in the form of angle sections of required sizes of plain angles.

3.1.1 Single angles

Three specimens were prepared one each for 2 mm 3 mm and 4 mm cold formed angle.

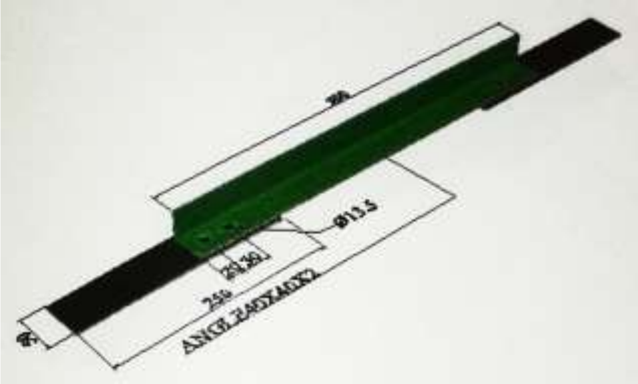

Figure 3.2 Details of single plain angle specimen provided with bolts in single row

3.1.2 Double Angles

In the second series of experimental program tests on double angles which were fabricated by bolting of two single angles to opposite side and to the same side of gusset plate were carried out.

Figure 3.3 Details of double angle specimen connected to opposite side provided with bolts in single row

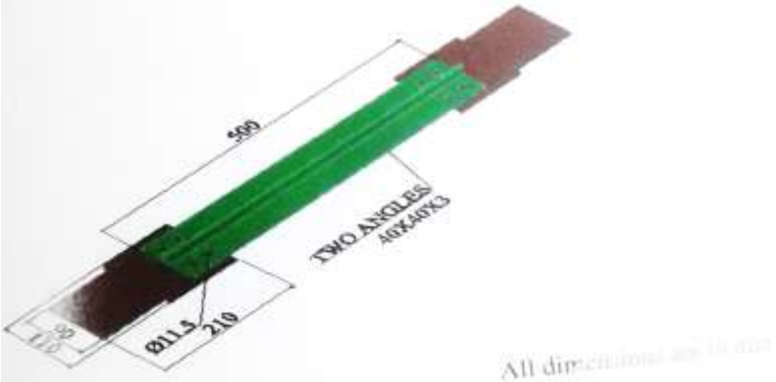

Figure 3.4 Details of double angle specimen connected to same side provided with bolts in single row

3.2 Experimental Observations

Ultimate Load Carrying Capacity

The experimental ultimate loads for all the cold-formed steel single and double angles are presented in table 1, 2, 3 and 4.

Table 5: Ultimate load carrying capacity and mode of failure of the single angle with single row of bolts

S. No.	Size of the specimen (mm)	Ultimate load carrying capacity (kn)	Mode of failure
1	40x40x2	3600	Net Section Fracture
2	40x40x3	4600	Net Section Fracture
3	40x40x4	6400	Block Shear Fracture

Table 6: Ultimate load carrying capacity and mode of failure of the double angle connected to opposite side of gusset plate

S. No.	Size of the specimen (mm)	Ultimate load carrying capacity (kn)	Mode of failure
1	40x40x2	6000	Net Section Fracture

2	40x40x3	8600	Net Section Fracture
3	40x40x4	11400	Net Section Fracture

Table 7: Ultimate load carrying capacity and mode of failure of the double angle connected to same side of gusset plate

S. No.	**Size of the specimen (mm)**	**Ultimate load carrying capacity (kgf)**	**Mode of failure**
1	40x40x2	6200	Net Section Fracture
2	40x40x3	8200	Net Section Fracture
3	40x40x4	11800	Net Section Fracture

Table 8: Net Section Efficiency and Failure Mode of Specimen

S. No.	**Specimen**	**Experimental Load**		**Theoretical Load (kN)**	**Net Section Efficiency (% age)**	**Failure Mode**
		(kgf)	**(kN)**			
1	40x40x2 SA	3600	35.316	40.319	87.6%	Net Section Fracture
2	40x40x3 SA	4600	45.126	53.76	83.9%	Net Section Fracture
3	40x40x4 SA	6400	62.784	73.925	84.9%	Block Shear Fracture
4	40x40x2 DAOS	6000	58.86	80.638	73.0%	Net Section Fracture
5	40x40x3 DAOS	8600	84.366	107.52	78.5%	Net Section Fracture
6	40x40x4 DAOS	11400	111.834	147.85	75.6%	Net Section Fracture
7	40x40x2 DASS	6200	60.822	80.638	75.4%	Net Section Fracture
8	40x40x3 DASS	8200	80.442	107.52	74.8%	Net Section Fracture
9	40x40x4 DASS	11800	115.758	147.85	78.3%	Net Section Fracture

RESULTS AND DISCUSSION

This topic comprises of major findings and discussion based on following objectives of the study

1. To study the behavior of bolted connection in cold-formed steel single members under tension.
2. To study the behavior of bolted connection in cold-formed steel double angle members under tension (connected to opposite side of gusset plate)
3. To study the behavior of bolted connection in cold-formed steel double angle members under tension (connected to same side of gusset plate)
4. To compare the experimental results with the results predicted theoretically by mechanical properties of cold-formed steel members

Table 9: The behavior of bolted connection in cold-formed steel single members under tension

S. No.	**Specimen**	**Net Section Efficiency (% age)**	**Failure Mode**
1	40x40x2 Single angle	87.6%	Net Section Fracture
2	40x40x3 Single angle	83.9%	Net Section Fracture
3	40x40x4 Single angle	84.9%	Block Shear Fracture

Table 10: The behavior of bolted connection in cold-formed steel double angle members under tension (connected to opposite side of gusset plate)

S. No.	Specimen	Net Section Efficiency (% age)	Failure Mode
1	40x40x2 Double angle opposite side	73.0%	Net Section Fracture
2	40x40x3 Double angle opposite side	78.5%	Net Section Fracture
3	40x40x4 Double angle opposite side	75.6%	Net Section Fracture

Table 11: The behavior of bolted connection in cold-formed steel double angle members under tension (connected to same side of gusset plate)

S. No.	Specimen	Net Section Efficiency (% age)	Failure Mode
1	40x40x2 Double angle same side	75.4%	Net Section Fracture
2	40x40x3 Double angle same side	74.8%	Net Section Fracture
3	40x40x4 Double angle same side	78.3%	Net Section Fracture

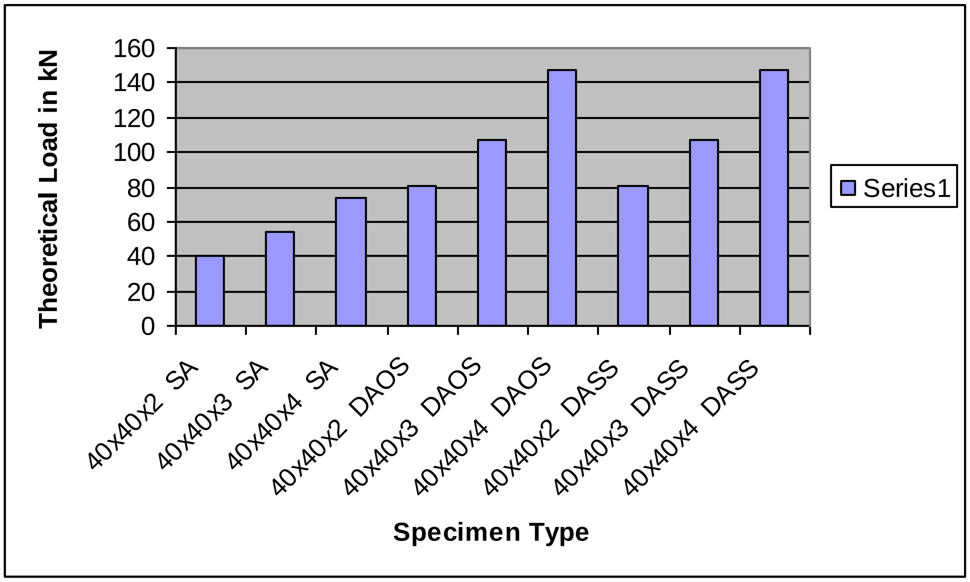

Figure 4.1: Comparison of experimental load for different specimen

Figure 4.1 depicts the experimental load for various specimens; it shows the experimental load progressively increases as the sheet metal thickness increases for a particular type of arrangement of member.

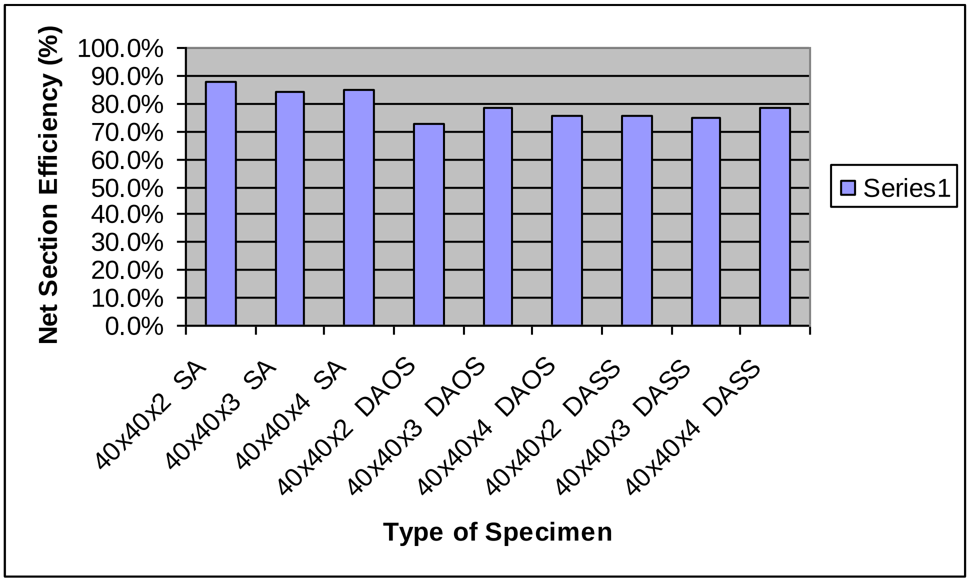

Figure 4.2: Comparison of net section efficiency for different specimen

Figure 4.2 depicts the Net section efficiency for various specimen, it shows that the net section efficiency is larger for single angle specimen as compared to double angle specimen.

CONCLUSIONS

Tension members are used in a variety of structures such as trusses, transmission towers etc. The most widely used structural shaped are the angle sections and the channel sections. Angles may be used as single angles or double angles and the connection may be bolted or welded. For practical reasons, it is unusual to connect the entire cross-section of the angle to the gusset plate. As a result, highly non uniform stresses will be generated near the connection, and this can cause localized yielding in parts of the cross-section. Thus the whole cross-section may not be fully utilized which causes a reduction in the net section efficiency. This loss of efficiency of the section is due to shear lag. An accurate estimation of this non-uniform stress distribution is necessary for determination of load carrying capacity of angles under tension.

The main objective of the study is to investigate the behaviour of cold formed steel single and double angles with bolted connections subjected to tension. Experimental investigations were carried out for the material available in Central Workshop of Bhilai Institute of Technology Durg.

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
- Behaviour of these elements in trusses and structures can be studied.
- Experiments can be conducted on bolted cold-formed steel channel sections to study the behaviour.
- The behaviour of welded cold-formed angles may be studied in detail.

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