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COMPARISON BETWEEN EXPERIMENTAL AND ANALYTICAL INVESTIGATION OF COLD FORMED STEEL ANGLE SECTIONS

Paul Makesh A[1], Arivalagan S[2]

[1] Research Scholar, Dept. of Civil Engineering, Dr.M.G.R Educational and Research Institute University, India
Professor and Dean, Dept of Civil Engineering, Dr.M.G.R Educational and Research Institute University, India

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Abstract - *Structural behavior of cold formed steel angle sections are tested into two methods, 1.experimentalinvestigations and Analytical Investigations (various international codes).Specimens were fabricated four different types of thickness in cold formed steel angle plain sections and cold formed steel angle lipped sections. In which 108 specimens were carried out on tension members fastened with bolts. Experimental results of the ultimate strength were compared with various international codes. British standard BS: 5950 - 1998 (Part 5), American Iron and Steel Institute AISI manual - 2001, and Australian / New Zealand standards AS/NZS: 4600-2005.*

Key Words: Cold formed steel, BS 5950-1998, AS/NZS: 4600 – 2005, AISI: 2001 (manual)

1. INTRODUCTION

Cold Formed Steel (CFS) is the common term for products made by rolling or pressing steel into semi-finished or finished goods at relatively low temperatures. In the construction industry, both structural and non-structural elements are created from thin gauges of sheet steel. These building materials encompass columns, beams, joists, studs, floor decking, built-up sections and other components. The thickness of steel members ranges from 0.4 mm to 6.4 mm. The cold forming operation increases the yield point and the ultimate strength of the steel sections. Cold formed steel members can be produced in a wide variety of sectional profiles such as angles, channels, hat sections, zed sections and sigma sections. Angles are the most common structural shape found in almost any structure due to their simplicity and ease of fabrication and erection. In building construction, cold-formed steel products can be classified into three categories: members, panels, and prefabricated assemblies. Prefabricated cold-formed steel assemblies include roof trusses, panellized walls or floors, and other prefabricated structural assemblies.

1.1 Economy of cold formed steel

Light steel framing using the cold-formed Steel (CFS) sections is one of the Industrialized Building System that highly recommended into our construction industry. Industrial Building System is not just speed up the construction time and reducing material usage, but also guaranteed the quality of the building, e.g., in acoustic and heat performance. The use of CFS as light steel framing system has not been popular as a preferred option in construction practice in Indonesia and Malaysia. Therefore, there is a need to investigate the economic aspects of the CFS as light steel framing system in our local industry, conduct comprehensive testing and parametric studies to create the guidance and procedures of the analysis and design of such building.

1.2 Structural behavior of cold formed steel

The resulting stress distribution justified the block shear strength equation by use of area along the gross shear plane. The von Mises stresses indicate that block shear failure might occur in a two bolt connection, and net section failure might occur in three and four bolts connection. The factor of safety for angles under tension in the limit state format giving due considerations to block shear failure and yielding of gross section was obtained. The knowledge and understanding of the behaviour of cold-formed steel bolted connections to determine tensile capacity, bearing capacity and the interaction of tension and bearing capacities were performed.

2. CODAL PROVISIONS

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.

2.1 Allowable Stress Design (ASD)

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".

2.2 Importance of Limit State Design

Ductile structural materials such as steel can withstand strains much larger than those encountered within the elastic limit. Design methods, which are based on elastic limit, fail to take advantage of the ability of such material to carry stresses above the yield stresses (strain hardening).

2.3 Load carrying capacity

The following codal provisions are used to predict member capacities of the single and double angle members of American Iron and Steel Institute, the Australian / New Zealand Standards, and British Standards.

2.3.1 Indian Standards, IS: 800 – 2007

2.3.1.1 Gross section yielding

Steel members can sustain loads up to the ultimate load without failure. However, the members will elongate considerably at this load, and hence make the structure unserviceable. The design strength T_{dg} is limited to the yielding of gross cross section which is given by:

$T_{dg} = f_y A_g / \gamma_{m0}$

where,

f_y = yield strength of the material in M_{Pa}, A_g = gross area of cross section in mm^2.

γ_{m0}= 1.10 partial safety factor for failure at yielding.

2.3.1.2 Net section rupture

When the tension member with a hole is loaded statically, the point adjacent to the hole reaches the yield stress fy. On further loading, the stress in other fibers away from the hole progressively reaches the yield stress f_y. Deformations of the member continue with increasing load until final rupture of the member occurs when the entire net cross section of the member reaches the ultimate stress fu. The rupture strength of an angle connected through one leg is affected by shear lag. The design strength T_{dn}, as governed by rupture at net section is given by:

$T_{dn} = 0.9\ f_u\ A_{nc} / \gamma_{m1} + \beta\ A_{go}\ f_y / \gamma_{m0}$

where,

$\beta = 1.4 – 0.076\ (w/t)\ (f_y / f_u)\ (b_s / L_c) \leq f_u\ \gamma_{m0} / f_y\ \gamma_{m1} \geq 0.7$

where,

w = outstand leg width bs = shear lag width

L_c = Length of the end connection, i.e., distance between the outermost bolts in the end joint measured along the load direction or length of the weld along the load direction.

2.3.1.3 Block shear failure

Block shear failure is considered as a potential failure mode at the ends of an axially loaded tension member block shear strength T_{db}, of connection shall be taken as the smaller of:

$T_{db} = (A_{vg}\ f_y / (\sqrt{3}\ \gamma_{m0}) + f_u\ A_{tn} / \gamma_{m1})$ or

$T_{db} = (A_{vn}\ f_u / (\sqrt{3}\ \gamma_{m1}) + f_y\ A_{tg} / \gamma_{m0})$

where,

A_{vg}, A_{vn} = minimum gross and net area in shear along a line of transmitted force, respectively.

A_{tg}, A_{tn} = minimum gross and net area in tension from the bolt hole to the toe of the angle, end bolt line, perpendicular to the line of force.

f_u, f_y = ultimate and yield stress of the material respectively.

2.3.2 Australian and New Zealand standards, AS/NZS: 4600 – 2005

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

$N_t= A_g\ f_y$ (1), $N_t= A_n 0.85\ K_t\ A_n\ f_u$

where A_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, obtained by deducting from the gross area of the cross section, the sectional area of all penetrations and holes, including fastener holes mm^2

f_u= tensile strength used in the design, N/mm^2

2.3.2 American Iron and Steel Institute, AISI: 2001 (manual)

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

$P_n = A_n\ A_e f_u$

Where f_u= tensile strength of the connected part of a member, N/mm^2

$A_e= U\ A_n$ and $U = 1.0 - 0.36\ X / L < 0.9$ and $U > 0.5$

A_n= effective net sectional area of the member, mm^2

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

2.3.3 British Standard, BS: 5950 - 1998 (Part 5)

The tensile capacity Pt, of a member

$P_t = A_e * p_y$

Single angles

$A_e = a_1\ (3_{a1}+4_{a2}) / (3_{a1}+_{a2})$

Double angles

$A_e = a_1\ (5_{a1}+6_{a2}) / (5_{a1}+_{a2})$

For double angles connected to the same side of gusset plate the effective area can be determined as that of single angles. A_e = effective area of the section.

a_1 = the net sectional area of the connected leg.

a_2 = the gross sectional area of the unconnected leg.

Table 1 : Comparison of Experimental load and predicted ultimate load obtained by various international codes(1.5mm thick)

S. No	Size of specimen (mm)	Exp valve	*AS/NZS 4600: 2005*	AS/NZS/Exp	AISI 2007	AISI/ Exp	BS:5950 (Part 5) - 1998:	BS /Exp
1	50x50	27.54	24.18	0.88	28.44	1.03	26.09	0.95
2	60x60	32.45	29.80	0.92	35.06	1.08	32.56	1.00
3	70x70	36.75	35.42	0.96	41.67	1.13	39.01	1.06
4	50x50x10	36.28	28.68	0.79	33.74	0.93	28.02	0.77
5	60x60x10	42.58	34.30	0.81	40.35	0.95	34.63	0.81
6	70x70x10	48.56	39.92	0.82	46.97	0.97	41.31	0.85
7	50x50(o)	59.78	48.36	0.81	56.89	0.95	55.91	0.94
8	60x60(o)	64.58	59.60	0.92	70.12	1.09	58.30	0.90
9	70x70(o)	79.86	70.85	0.89	83.35	1.04	82.85	1.04
10	50x50(s)	56.78	48.36	0.85	56.89	1.00	55.91	0.98
11	60x60(s)	64.58	59.60	0.92	70.12	1.09	58.30	0.90
12	70x70 (s)	78.54	70.85	0.90	83.35	1.06	82.85	1.05
13	50x50x10(o)	69.74	57.35	0.82	67.47	0.97	60.54	0.87
14	60x60x10(o)	74.58	68.60	0.92	80.70	1.08	76.24	1.02
15	70x70x10(o)	97.87	79.84	0.82	93.93	0.96	88.17	0.90
16	50x50x10(s)	68.74	57.35	0.83	67.47	0.98	60.54	0.88
17	60x60x10(s)	80.47	68.60	0.85	80.70	1.00	76.24	0.95
18	70x70x10(s)	96.47	79.84	0.83	93.93	0.97	88.17	0.91
19	50x25	18.27	17.15	0.94	20.18	1.10	20.74	1.14
20	60x30	22.47	21.37	0.95	25.14	1.12	26.07	1.16
21	70x35	28.47	25.58	0.90	30.10	1.06	31.00	1.09
22	50x25x10	23.47	21.65	0.92	25.47	1.09	23.85	1.02
23	60x30x10	30.79	25.86	0.84	30.43	0.99	29.12	0.95
24	70x35x10	33.48	30.08	0.90	35.39	1.06	34.68	1.04
25	50x25	38.78	34.30	0.88	40.35	1.04	43.16	1.11
26	60x30	49.78	42.73	0.86	50.27	1.01	53.63	1.08
27	70x35	58.47	51.17	0.88	60.20	1.03	64.00	1.09
28	50x25	37.48	34.30	0.92	40.35	1.08	43.16	1.15
29	60x30	49.72	42.73	0.86	50.27	1.01	53.63	1.08
30	70x35	58.78	51.17	0.87	60.20	1.02	64.00	1.09
31	50x25x10(o)	50.43	43.30	0.86	50.94	1.01	51.24	1.02
32	60x30x10(o)	54.58	51.73	0.95	60.86	1.12	43.63	0.80
33	70x35x10(o)	70.59	60.16	0.85	70.78	1.00	73.03	1.03
34	50x25x10(s)	51.58	43.30	0.84	50.94	0.99	51.24	0.99
35	60x30x10(s)	60.72	51.73	0.85	60.86	1.00	43.63	0.72
36	70x35x10 (s)	70.58	60.16	0.85	70.78	1.00	73.03	1.03

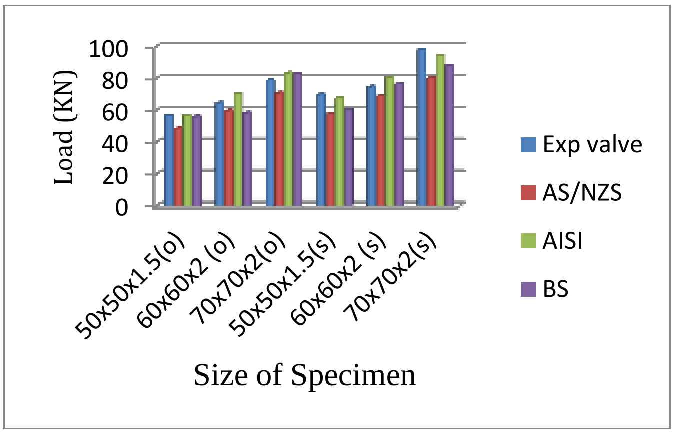

Chart – 1 Comparison of ultimate load with load based on codal provision for Double angles connected to opposite side and same side of the gussets plate. (1.5mm)

Table 2 : Comparison of Experimental load and predicted ultimate load obtained by various international codes(1.6mm thick)

Size of specimen (mm)	Exp valve	*AS/NZS 4600: 2005*	AS/NZS/Exp	AISI 2007	AISI/ Exp	BS:5950 (Part 5) - 1998:	BS /Exp
50x50	29.45	26.11	0.89	30.71	1.04	28.17	0.96
60x60	34.56	32.18	0.93	37.85	1.10	35.15	1.02
70x70	40.58	38.25	0.94	45.00	1.11	42.12	1.04
50x50x10	39.15	30.96	0.79	36.43	0.93	30.25	0.77
60x60x10	46.78	37.03	0.79	43.57	0.93	37.39	0.80
70x70x10	52.58	43.10	0.82	50.71	0.96	44.60	0.85
50x50(o)	62.58	52.21	0.83	61.42	0.98	60.37	0.96
60x60(o)	68.41	64.35	0.94	75.71	1.11	62.95	0.92
70x70(o)	84.59	76.50	0.90	89.99	1.06	89.46	1.06
50x50(s)	62.58	52.21	0.83	61.42	0.98	60.37	0.96
60x60(s)	76.24	64.35	0.84	75.71	0.99	62.95	0.83
70x70 (s)	84.25	76.50	0.91	89.99	1.07	89.46	1.06
50x50x10(o)	76.28	61.92	0.81	72.85	0.96	65.37	0.86
60x60x10(o)	82.58	74.07	0.90	87.14	1.06	82.31	1.00
70x70x10(o)	103.5	86.21	0.83	101.4	0.98	95.20	0.92
50x50x10(s)	76.42	61.92	0.81	72.85	0.95	65.37	0.86
60x60x10(s)	88.48	74.07	0.84	87.14	0.98	82.31	0.93
70x70x10(s)	106.5	86.21	0.81	101.4	0.95	95.20	0.89
50x25	21.58	18.52	0.86	21.78	1.01	22.40	1.04
60x30	25.46	23.07	0.91	27.14	1.07	28.15	1.11
70x35	32.45	27.62	0.85	32.50	1.00	33.47	1.03
50x25x10	28.11	23.37	0.83	27.50	0.98	25.75	0.92
60x30x10	31.44	27.93	0.89	32.86	1.05	31.44	1.00
70x35x10	39.58	32.48	0.82	38.21	0.97	37.44	0.95
50x25	40.48	37.03	0.91	43.57	1.08	46.60	1.15
60x30	57.48	46.14	0.80	54.28	0.94	57.90	1.01
70x35	67.41	55.25	0.82	65.00	0.96	69.10	1.03
50x25	41.33	37.03	0.90	43.57	1.05	46.60	1.13
60x30	52.58	46.14	0.88	54.28	1.03	57.90	1.10
70x35	68.47	55.25	0.81	65.00	0.95	69.10	1.01
50x25x10(o)	58.45	46.75	0.80	55.00	0.94	55.33	0.95
60x30x10(o)	68.45	55.85	0.82	65.71	0.96	47.10	0.69
70x35x10(o)	81.54	64.96	0.80	76.42	0.94	78.85	0.97
50x25x10(s)	56.18	46.75	0.83	55.00	0.98	55.33	0.98
60x30x10(s)	67.28	55.85	0.83	65.71	0.98	47.10	0.70
70x35x10 (s)	81.59	64.96	0.80	76.42	0.94	78.85	0.97

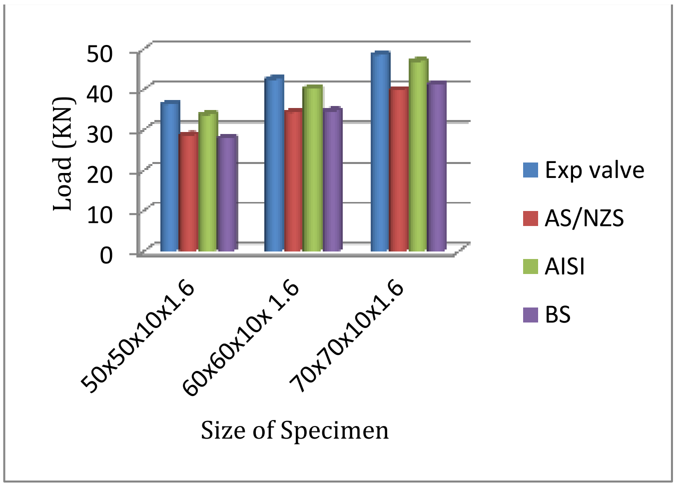

Chart – 2 Comparison of ultimate load with load based on codal provision for single plane angles with Lip (1.6mm)

Table 3 : Comparison of Experimental load and predicted ultimate load obtained by various international codes (2mm thick)

S. No	Size of specimen (mm)	Exp valve	*AS/NZS 4600: 2005*	AS/NZS/Exp	AISI 2007	AISI/ Exp	BS:5950 (Part 5) - 1998:	BS /Exp
1	50x50	34.58	33.16	0.96	39.01	1.13	35.78	1.03
2	60x60	38.13	40.87	1.07	48.08	1.26	44.65	1.17
3	70x70	45.26	48.58	1.07	57.15	1.26	53.50	1.18
4	50x50x10	41.25	39.33	0.95	46.27	1.12	38.42	0.93
5	60x60x10	51.47	47.04	0.91	55.34	1.08	47.50	0.92
6	70x70x10	62.47	54.75	0.88	64.41	1.03	56.65	0.91
7	50x50(o)	75.48	66.32	0.88	78.02	1.03	76.68	1.02
8	60x60(o)	87.29	81.74	0.94	96.16	1.10	79.96	0.92
9	70x70(o)	108.1	97.16	0.90	114.3	1.06	113.6	1.05
10	50x50(s)	80.47	66.32	0.82	78.02	0.97	76.68	0.95
11	60x60(s)	92.58	81.74	0.88	96.16	1.04	79.96	0.86
12	70x70 (s)	112.2	97.16	0.87	114.3	1.02	113.6	1.01
13	50x50x10(o)	86.27	78.65	0.91	92.53	1.07	83.03	0.96
14	60x60x10(o)	92.47	94.08	1.02	110.6	1.20	104.5	1.13
15	70x70x10(o)	117.2	109.5	0.93	128.8	1.10	120.9	1.03
16	50x50x10(s)	87.46	78.65	0.90	92.53	1.06	83.03	0.95
17	60x60x10(s)	98.75	94.08	0.95	110.6	1.12	104.5	1.06
18	70x70x10(s)	112.1	109.5	0.98	128.8	1.15	120.9	1.08
19	50x25	28.17	23.52	0.83	27.67	0.98	28.45	1.01
20	60x30	32.78	29.30	0.89	34.47	1.05	35.76	1.09
21	70x35	37.85	35.09	0.93	41.28	1.09	42.52	1.12
22	50x25x10	42.58	29.69	0.70	34.93	0.82	32.71	0.77
23	60x30x10	48.75	35.47	0.73	41.73	0.86	39.94	0.82
24	70x35x10	53.78	41.25	0.77	48.54	0.90	47.56	0.88
25	50x25	59.76	47.04	0.79	55.34	0.93	59.19	0.99
26	60x30	73.7	58.61	0.80	68.95	0.94	73.55	1.00
27	70x35	87.81	70.17	0.80	82.56	0.94	87.77	1.00
28	50x25	58.81	47.04	0.80	55.34	0.94	59.19	1.01
29	60x30	62.78	58.61	0.93	68.95	1.10	73.55	1.17
30	70x35	83.47	70.17	0.84	82.56	0.99	87.77	1.05
31	50x25x10(o)	72.37	59.38	0.82	69.85	0.97	70.28	0.97
32	60x30x10(o)	89.34	70.94	0.79	83.46	0.93	59.83	0.67
33	70x35x10(o)	106.3	82.51	0.78	97.07	0.91	100.1	0.94
34	50x25x10(s)	71.58	59.38	0.83	69.85	0.98	70.28	0.98
35	60x30x10(s)	83.14	70.94	0.85	83.46	1.00	59.83	0.72
36	70x35x10 (s)	92.47	82.51	0.89	97.07	1.05	100.1	1.08

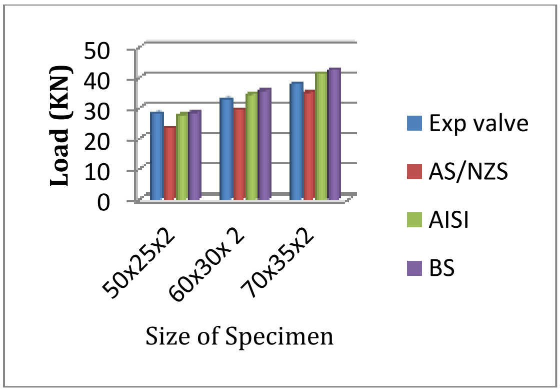

Chart – 3 Comparison of ultimate load with load based on codal provision for single plane unequal angles (2mm)

Table 4: Comparison of Experimental load and predicted ultimate load obtained by various international codes (3mm thick)

Size of specimen (mm)	Exp valve	*AS/NZS 4600: 2005*	AS/NZS/Exp	AISI 2007	AISI/ Exp	BS:5950 (Part 5) - 1998:	BS /Exp
50x50	54.28	51.91	0.96	61.07	1.13	56.01	1.03
60x60	68.45	63.98	0.93	75.27	1.10	69.90	1.02
70x70	82.45	76.05	0.92	89.47	1.09	83.76	1.02
50x50x10	78.25	61.57	0.79	72.43	0.93	60.15	0.77
60x60x10	94.28	73.64	0.78	86.63	0.92	74.36	0.79
70x70x10	102.5	85.71	0.84	100.8	0.98	88.69	0.86
50x50(o)	124.2	103.82	0.84	122.1	0.98	120.0	0.97
60x60(o)	168.2	127.96	0.76	150.5	0.89	125.1	0.74
70x70(o)	154.	152.10	0.99	178.9	1.16	177.8	1.15
50x50(s)	113.2	103.82	0.92	122.1	1.08	120.0	1.06
60x60(s)	143.5	127.96	0.89	150.5	1.05	125.1	0.87
70x70 (s)	152.2	152.10	1.00	178.9	1.18	177.8	1.17
50x50x10(o)	105.2	123.13	1.17	144.8	1.38	129.9	1.23
60x60x10(o)	131.2	147.27	1.12	173.2	1.32	163.6	1.25
70x70x10(o)	168.2	171.42	1.02	201.6	1.20	189.3	1.12
50x50x10(s)	122.4	123.13	1.01	144.8	1.18	129.9	1.06
60x60x10(s)	142.5	147.27	1.03	173.2	1.22	163.6	1.15
70x70x10(s)	149.2	171.42	1.15	201.6	1.35	189.3	1.27
50x25	40.87	36.82	0.90	43.32	1.06	44.54	1.09
60x30	53.28	45.87	0.86	53.97	1.01	55.98	1.05
70x35	68.57	54.93	0.80	64.62	0.94	66.56	0.97
50x25x10	55.28	46.48	0.84	54.68	0.99	51.21	0.93
60x30x10	68.87	55.53	0.81	65.33	0.95	62.52	0.91
70x35x10	78.27	64.58	0.83	75.98	0.97	74.45	0.95
50x25	88.25	73.64	0.83	86.63	0.98	92.66	1.05
60x30	108.4	91.74	0.85	107.9	1.00	115.1	1.06
70x35	138.6	109.85	0.79	129.2	0.93	137.4	0.99
50x25	93.28	73.64	0.79	86.63	0.93	92.66	0.99
60x30	97.58	91.74	0.94	107.9	1.11	115.1	1.18
70x35	128.7	109.85	0.85	129.2	1.00	137.4	1.07
50x25x10(o)	104.3	92.95	0.89	109.3	1.05	110.0	1.05
60x30x10(o)	139.9	111.06	0.79	130.6	0.93	93.66	0.67
70x35x10(o)	151.0	129.17	0.86	151.9	1.01	156.7	1.04
50x25x10(s)	118.2	92.95	0.79	109.3	0.92	110.0	0.93
60x30x10(s)	122.8	111.06	0.90	130.6	1.06	93.66	0.76
70x35x10 (s)	147.2	129.17	0.88	151.1	1.03	156.7	1.06

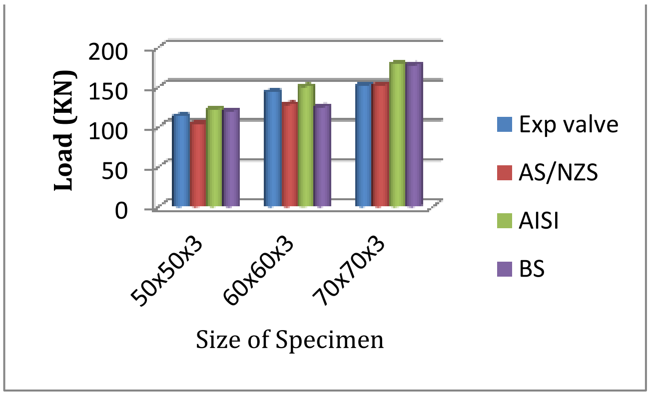

Chart – 4 Comparison of ultimate load with load based on codal provision for Double plane angles with Lip (3mm)

3. EXPERIMENTAL INVESTIGATIONS

In the present investigation, experiments were conducted to study the structural behavior of bolted connections in 108 specimen numbers of cold formed steel single and double angle sections. A series of tension tests were conducted on specimens and their behavior was observed in the elastic and plastic ranges of loading. The specimens are used in the present investigation were fabricated from steel sheets of four different thicknesses 1.5mm, 1.6mm, 2mm, and 3mm by bending and press breaking operations. The length of gusset plate was provided according to the requirement of pitch and edge distance as per Indian code of practice. 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.

4. ANALYTICAL INVESTIGATIONS

The behavior of cold-formed steel single and double angles section when subjected to eccentric tension were studied. The effect of shear lag which depends on the geometry of the cross-section and disposition of the angle on the load carrying capacity was studied. The ultimate load carrying capacities of the specimens were compared with the load carrying capacities using the American, Australian/New Zealand and British standards.

5. CONCLUSIONS

Experimental results were observed that the ultimate loads obtained from various international codes of thickness 1.5, 1.6, 2 and 3mm. The single equal plain angles loads are 10% lower than the experimental loads values using AISI manual-2001.

Similarly, in case of single equal plain angle loads are 11% lower than that of the experimental loads values using AS/NZS: 4600-2005. To review that in the case of single equal angles that values from various codes are 16% lower than experimental values

Experimental and ultimate loads obtained by various international codes of thickness 1.5, 1.6, 2 and 3mm. To observed the double equal plain angles opposite side the predicted loads are 12% lower than the experimental loads values using AISI manual-2001.

Similarly, in case of Double equal plain angles opposite side the predicted loads are 14% lower than that of the experimental loads values using AS/NZS: 4600-2005. To review that in the case of Double equal plain angles opposite side the predicted values are 18% lower than experimental values using BS:5950 - 1998 (Part 5).

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