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Analysis and Design of Cold-Formed Z Purlins

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Abstract: Structures built by cold-formed segments of primary members secondary members and roof panels provide a different solution for a great variety of areas such as housing, storage, education, etc The design of cold-formed sections has obvious complexity in view of the buckling of sections vis-à-vis stress in the compression element, especially in flexure. In this study, effective section properties of the Z section are calculated for a wide range of configurations with different b/t ratios for flange subjected to maximum allowable stress. The section properties are being used to develop the optimum section configurations for constructing a structure in different regions. . The study gives different formulae for quick assessment of parameters and also presents simple design tools and a few standard cold-formed sections having similar configuration but for thickness to be used for residential or community shelters for different zones. Recourse is made to compare the results with similar studies using AISI code and compare the results of lapped purlin and purlin without laps design. The whole course is mainly focused on analyzing and designing cold-formed section purlin.
Keywords: Cold-formed section, Z purlin, section properties, lap, deflection

I. INTRODUCTION

Two core types of steel segments arc presently used in building construction, explicitly, the hot-rolled and cold-formed sections. The use of cold-formed steel segments has increased considerably as the world steel industry moves from the production of hot-rolled segments and hot-rolled plates to coil and strip, often with galvanized and painted coaling. Compared with conventional hot-rolled steel members, the cold-formed steel members gain enhancement of tensile properties after cold-forming, decrease weight (higher strength to weight ratio), and quicker and easier installation. Unlike hot-rolled steel sections, the cold-formed steel sections arc usually slender and not doubly symmetric and subsequently, they're prone to a range of complex buckling modes and their interactions

Fig. 1 Cold-formed steel structure

Cold form sections have primary members and secondary members that provide a broad range of implementation in different sectors like health, education, housing, etc. The cold-formed section has large flat width to thickness ratio and it leads to buckling of the element still, Cold-formed steel has the following intrinsic characteristics

1) Flexibility in designs.
2) Easy and fast manufacturing and erection.
3) Ease in transportation and handling.
4) Economical and light in weight.
5) Low maintenance.
6) Easy future expansion.

TABLE 1
Merits of cold-formed steel over hot-rolled steel

Sr. no.	Parameters	Hot rolled steel	Cold-rolled steel
1	Design	It is designed as simply supported.	It is either by the continuous beam.
2	Max. Moment	Its maximum moment at mid-span.	The maximum moment at support. Therefore deflection reduces
3	Weight	Very heavy i.e. For a 7.5mm span ISMC 125 will be used @11.27 kg/m	Z section 1.5 mm thick 200z1.5 configuration 200x60x20 @4.2 kg
4	Execution	It becomes heavier and cumbersome.	It becomes easy.
5	Designed	Normally designed as fully unbraced for uplift.	Sag rods are provided to reduce the unbraced length
6	Sag rods	No-sag rods. Therefore alignment becomes difficult.	Sag rods help in alignment.
7	Connection	Connection to rafter by welded clips.	Can be directly connected by bolts to welding.
8	Grade of steel	Grade of steel available only Fy250 mpa	Grade of steel normally 350 used even 250 can be used.
9	Galvanization	Only a hot-dipped galvanization is a very costly option.	Pre-galvanized materials are available is the norm.
10		For long-span have to change section itself	Just changing the thickness from 1.5 mm to 2mm is sufficient.

Cold-formed section forming methods
Three methods are generally used in the manufacture of cold-formed sections are

- Cold roll forming
- Press brake operation
- Bending brake operation

II. PURLINS

[2][5] Purlins are used as secondary roof members which must support the cladding against the action of the wind and the snow load. cold-formed steel (CFS) Z-shaped purlins have been extensively used as a primary component in metal roof systems for low-rise industrial and commercial buildings around the world. Lapped joints with bolted connections are one of the most popular design solutions for providing the continuity of purlins in the multi-span roof system.

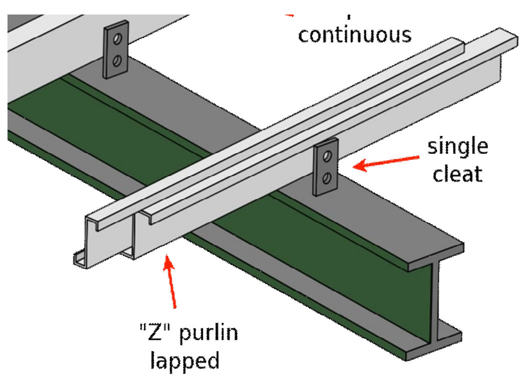

Fig. 2 Z section Purlin

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Cold-formed steel purlins are generally utilized in roof systems because of their high structural efficiency. cold-framed steel purlins C and Z sections, and the part normally ranges from 100 to 350 mm while the thicknesses range from 1.2 to 3.0 mm. yield strength is between 280 and 350 N/mm2, however, nowadays segments with yield strength up to 450 N/mm2 might be viewed as some respectability purlin frameworks giving superior load-carrying capacities. As of now, four various kinds of purlin frameworks are generally found with various levels of continuity (i) single-span, (ii) Double span, (iii) multi-span with sleeves (iv) multi-span with overlaps

A. Plan for Continuity of purlin

To accomplish some level of continuity, cold-formed members are lapped and anchored together for a distance of not less than 600 mm; i.e., every section extends out somewhere around 300 mm. (Hypothetically 609.6mm and 304.8mm, and Standard Indian practice 706mm and 353mm). The level of continuity might be expanded with a more extended (long) lap distance, though at an expense of the additional material utilized in the lap. Continuous purlins are subject to varying bending moments at different spans, even from uniform loads. The most critical bending stress is a continuous beam that occurs at the end spans. It follows that the end purlins must have stronger sections than the inner ones. Some producers select to make use of the equal purlins all through the construction and offer extra splice lengths for end bay purlins. But it can suggest a few value performances have been forgone and all of the purlins saved to the dimensions managed via way of means of the end span.

III.DESIGN METHODOLOGY

The gross sectional properties and effective sectional properties of the following sectional configuration are calculated and compared,

TABLE 2
Sectional configuration used for theoretical investigation

Depth (mm)	Width (mm)	Lip (mm)	Thickness (mm)
200	60	18	1.5
	65	20	1.6
	70	22	1.75
	75	24	1.8
	80	26	2.0
	85	28	2.1
	90	30	2.2
			2.5

[11] In the analysis, the effective section properties were calculated by using the effective widths of single members. For example from the below fig 3, let us consider the abcdef compression element. Effective parts are highlighted. Section A1, the parts A-1, 2-3, 4-5, 6-7, and 8-F are regarded as being ineffective in resisting compression. As a general rule, the portions located close to the supported edges are effective. Note That in the case of compression members, all elements are subject to reductions in width.
In the case of flexural members, in most cases, only the compression elements are considered to have effective widths

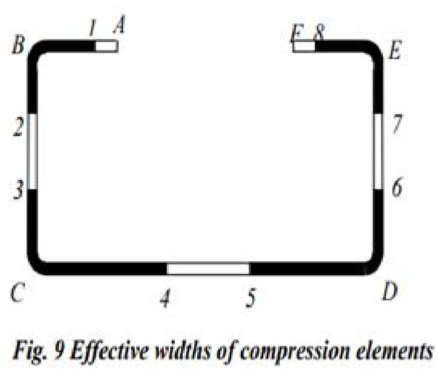
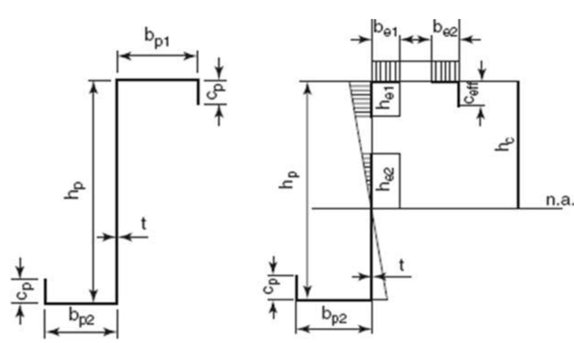


Fig. 3 A Open box section



(a) Gross width (b) Effective width

Fig 4 Z section purlin gross width and effective width

IV. THEORETICAL ANALYSIS

The theoretical study involves the analysis and design 'Z' shaped purlin section. Calculations are done as per codal provisions of Indian standard IS 801-1975 and American standard AISI 2008 for effective width, for designing IS 801-1975 is taken.

A. Based on the procedure, checks and calculations are done with different section configurations.

1) Effective width calculation By IS 801- 1975

Elements without intermediate stiffener

Considering section Z1 with following detail

Overall depth (d) = 200 mm

Flange width (b) = 60 mm

Lip length (l) = 20 mm

Thickness (t) = 1.5 mm

Radius of curvature = 3.0 mm

For load determination

Flanges are fully effective (b=w) upto $(w/t)_{hm} = 1435/\sqrt{f}$

Where,

(w/t) = flat-width ratio

b = effective design width in cm

f = actual stress in the compression element computed on the basis of the effective design width in kgf/cm^2.

f= 345 MPa = 345* 9.81 = 3384.45 kgf/cm^2.

= $\sqrt{f} = \sqrt{3384.45} = 58.18$ kgf/cm^2.

Flat width = w = B - [2(r+t)] = 60 - [2(3+1.5)] = 51mm

Flat width = w = 51mm

$(w/t)_{lim} = 1435/\sqrt{f}$ i.e., $(w/t)_{lim} = 1435/\sqrt{F}$ then, b = w

$(w/t) = 51 / 1.5 = 34 > (w/t)_{lim} = 24.67$

If $(w/t)_{cal} > 1435/\sqrt{f}$ then effective width is calculated by

$$\frac{b}{t} = \frac{2120}{\sqrt{f}}\left[1 - \frac{465}{\left(\frac{w}{t}\right)\sqrt{f}}\right]$$

$$\frac{b}{t} = \frac{2120}{\sqrt{345 * 9.81}}\left[1 - \frac{465}{\left(\frac{51}{1.5}\right)\sqrt{345} * \sqrt{9.81}}\right]$$

$$\left(\frac{b}{t}\right) = 27.87$$

b = 27.87*1.5 = 41.81 mm

Width lost in buckling under loading = 51- 41.81 = 9.19 mm

For deflection determination

Flanges are fully effective (b=w) upto $(w/t)_{lim} = 1850/\sqrt{f}$

Flat width = w = B - [2(r+t)] = 60 - [2(3+1.5)] = 51mm

Flat width = 51 mm

If $(w/t)_{lim} = 1850/\sqrt{f}$ i.e., $(w/t)_{lim} = \frac{1540}{\sqrt{f}}$ i.e., $(w/t)_{lim} = 31.80$

If $(w/t)_{lim} = 1850/\sqrt{f}$ then, b = w

$(w/t) = 51 / 1.5 = 34 > (w/t)_{lim} = 31.80$

If $(w/t)_{cal} > 1435/\sqrt{f}$ thcn effective width is calculated by

$$\frac{b}{t} = \frac{2710}{\sqrt{f}}\left[1 - \frac{600}{\left(\frac{w}{t}\right)\sqrt{f}}\right]$$

$$\frac{b}{t} - \frac{2120}{\sqrt{345 * 9.81}}\left[1 - \frac{600}{\left(\frac{51}{1.5}\right)\sqrt{345} * \sqrt{9.81}}\right]$$

$\left(\frac{b}{t}\right) = 32.45$

b = 32.45*1.5 b = 48.68 mm

2) Effective width calculation By AISI - 2008

Effective Section Properties

Overall depth (d) = 200 mm

Flange width (b) = 60 mm

Lip length (l) = 20 mm

Thickness (t) = 1.5 mm

Radius of curvature = 3.0 mm

Compression flange

w = b = B-[(r+(t/2)+(α x(r+(t/2) x (tan(γ/2)]

= 60 –[3.75+(1.5/2) + (1 x(3.75+(1.5/2) x tan(45/2)] =51.43

w/t = 51.34 / 1.5 = 34.29 < 60 OK

$S = 1.28\sqrt{E/F}$

$= 1.28 \times \sqrt{200000/345} = 30.18$

Hence w/t ≥ 0.328 S Check effective width of flange

Compute k of flange based on stiffener lip properties

$Ia = 399t^4 \left[\frac{w/t}{S} - 0.328\right]^3 \leq t4\left[115\,\frac{w/t}{S} - 5\right]$

$= 399t^4 \left[\frac{34.29}{30.18} - 0.328\right]^3 \leq t4\left[115\,\frac{34.29}{S} - 5\right]$

$= 976.09\ mm^4 > 673.12\ mm^4$ hence $Ia = 673.12\ mm^4$

d = c = α x (Lip-(r+t/2)x (tan(45/2)

= 1x (20- (3.75+1.5/2) x (tan(45/2) = 18.13

d = c = mm

$Is = (d^3\ t\ \sin^2(\theta))/12$

$= (18.13^3 \times 1.5 \sin^2(45))/12 = 529.88\ mm^4$

RI = Is/Ia ≤ 1

529.88 / 673.12 = 0.802

$n = 0.582^4 \left[0.582 - \frac{w/t}{4S}\right] \geq 1/3$

$= 0.582^4 \left[0.582 - \frac{34.29}{4x\ 30.18}\right] \geq 1/3$

= 0.303 < 1/3 < hence n = 1/3

D = 20 cm

D / w = 20 / 51.43 = 0.38 < 0.8 OK

$K = \left[4.82 - \frac{5D}{w}\right] (R_I)^n + 0.43 \leq 4$

$= \left[4.82 - \frac{5D}{34.29}\right] (0.802)^{1/3} + 0.43 = 3.10 \leq 4$

$Fcr = k \times \frac{\pi^{2x}E}{12(1-u^2)} (t/w)^2 = = k \times \frac{\pi^{2x}200000}{12(1-0.3^{\wedge}2} (1/34.29)^2 = 476.81$ M.Pa

$\lambda = \sqrt{\frac{f}{fcr}} = \sqrt{\frac{345}{476.81}} = 0.85$

= > hence flange is subject to local buckling

ρ = (1 - 0.22/λ) / λ = (1-0.22/0.85)/0.85 = 1.078

Effective width beff = ρw

= 1.078 * 51.34 = 55.45 mm.

B. Comparison of effective widths by Indian and American standard

The underlying boundaries, effective width to thickness, effective width to gross width, effective section modulus to gross section modulus, and compelling moment of inertia to the gross moment of inertia are determined and compared for Indian codes IS:801-1975.

Comparisons are done with computation according to AISI-2008.

The different combinations of sectional configurations are taken around 56 sets of sections are taken for comparison and evaluation of data with reference to that fast access of design parameters are mentioned further.

C. Comparision of design of purlin without laps and design of purlin with laps

1) Purlin data used for designing multi-span purlin

Span -- 7.75 m. (4 spans)
Spacing -- 1 m
Lap length -- 0.35 m. for single span
Number of sag rods -- 2
Slope -- 1:10

2) Load calculation

Dead load 0.9 KN/m
Axial load 5 KN/m
Live load 0.75 KN/m
Wind load 1.03 KN/m
External pressure coefficient 0.5
Internal pressure coefficient 0.93
Dead load
x-x Axis 0.89 KN/m
y-y Axis 0.0895 KN/m
Live load
x-x Axis 0.74 KN/m
y-y Axis 0.074 KN/m
Wind load
x-x Axis 1.47 KN/m
Load combination
DL+LL
x-x Axis 1.64 KN/m
y-y Axis 0.16 KN/m
DL+WL
x-x Axis 0.57 KN/m
Material properties
Yield strength 345 N/mm^2
Youngs modulus 200000 N/mm^2

As for this respective data design of purlin for without laps and with laps are completed and compared. Checks and deflection are calculated for a various number of sections. Some are mentioned below.

TABLE 3
Z purlin evaulavation checks

Z200x60x2.5	Purlin with laps		Purlin without laps
DL+LL	Span 1	Span 2	For all span
Moment			
Left support	--	0.46 OK	1.06 Not Ok
Left lap	--	0.75 OK	
Maximum	0.71 OK	0.32 OK	

Right lap	0.89 OK	0.53 OK	
Deflection			
Calculated	39.12	16.76	43.66
Allowable	51.66	51.66	51.66
	OK	OK	Not ok
DL+WL	Span 1	Span 2	
Moment			
Left support	--	0.16 OK	0.4 Ok
Left lap	--	0.25 OK	
Maximum	0.72 OK	0.15 OK	
Right lap	0.24 OK	0.18 OK	
Deflection			
Calculated	13.75	5.89	15.16
Allowable	51.66	51.66	51.66
	OK	OK	OK
Shear stress in web	0.25 Ok		0.34 Ok
Check for combined bending and shear in the web	0.415 Ok		0.60 Ok

For without lap purlin deflection mentioned is for total 4 spans and
For with laps span 1 and span 2 are mentioned other span 3 and span 4 are symmetrical with these Span1 and span2.

TABLE 4
Deflection of purlin without laps and with laps

Section	Span (mm)	Deflection (mm)		
		Without laps	With laps	
			Span1	Span2
200x60x18x1.5	6000	26.17	23.45	10.05
200x60x20x1.6		24.19	21.67	9.29
200x60x22x1.8		21.23	19.03	8.15
200x60x24x2.0		18.87	16.91	7.25
200x60x26x2.5		14.97	13.42	5.75
200x60x18x1.5	6500	36.05	32.30	13.84
200x60x20x1.6		33.32	29.85	12.79
200x60x22x1.8		29.25	26.20	11.23
200x60x24x2.0		25.99	23.29	9.98
200x60x26x2.5		20.63	18.48	7.92
200x60x18x1.5	7000	48.49	43.44	18.62
200x60x20x1.6		44.82	40.15	17.21
200x60x22x1.8		39.34	35.25	15.11
200x60x24x2.0		34.96	31.33	13.43
200x60x26x2.5		27.74	24.86	10.65
200x60x18x1.5	7500	63.89	57.25	24.54
200x60x20x1.6		59.06	52.92	22.68
200x60x22x1.8		51.84	46.45	19.91
200x60x24x2.0		46.08	41.28	17.69
200x60x26x2.5		36.56	32.76	14.04

V. RESULT

Graphical representation of calculated data

A. Graphical Representations Of The Various Structural Parameters Are Shown Further

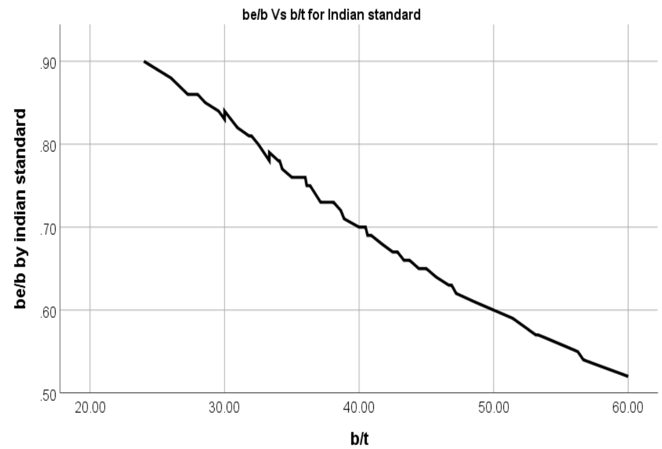


Fig. 5 be/b Versus b/t for Indian code IS801-1975

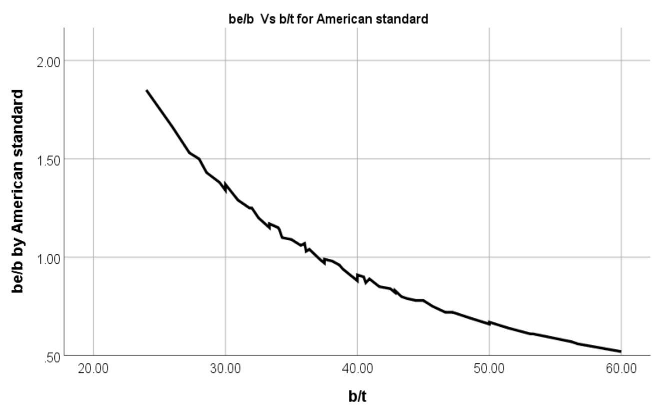


Fig. 6 be/b Versus b/t for American code AISI-2008

- Fig. 5 and Fig.6 shows that with the increase in b/t ratio, be/b decreases for IS code and AISI code respectively.

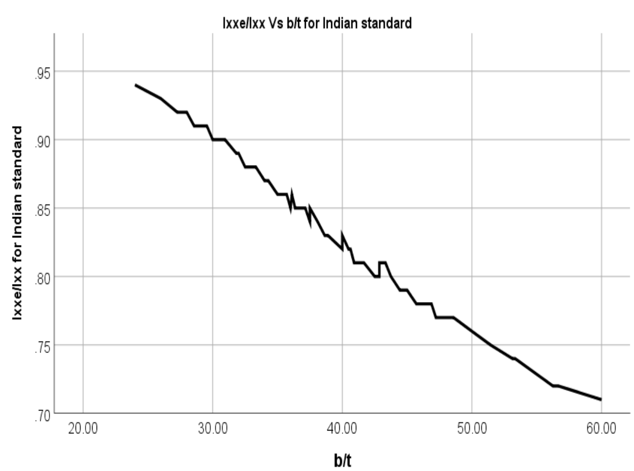


Fig. 7 b/t Versus Ixxe/Ixx for Indian code IS801-1975

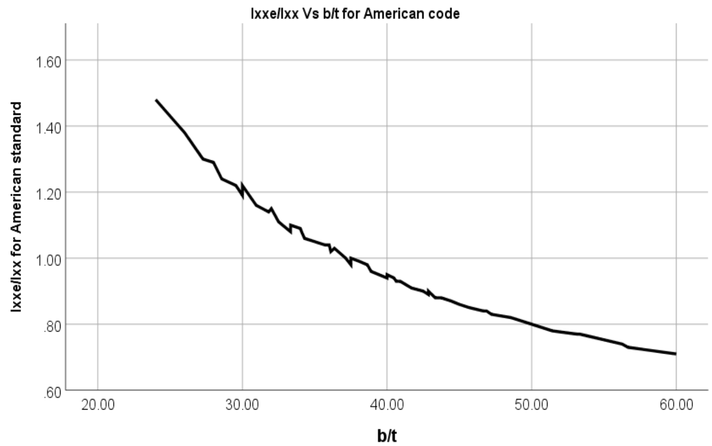


Fig. 8 b/t Versus Ixxe/Ixx for American code AISI-2008

- Fig. 7 and Fig.8 shows that with the increase in b/t ratio, Ixxe/Ixx becomes varies between 0.75 to 1.40 and gets decreased for IS code and AISI code respectively.

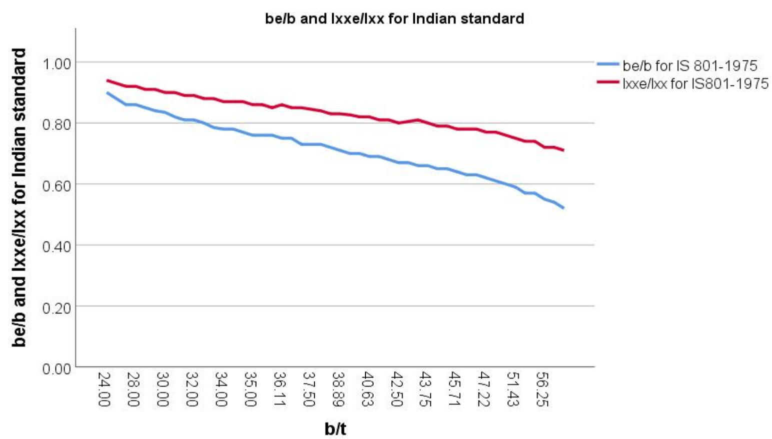


Fig. 9 b/t Versus be/b and Ixxe/Ixx for Indian code IS801-1975

- Fig. 9 shows that be/b for American code is on higher side of Indian code Versus b/t ratio.

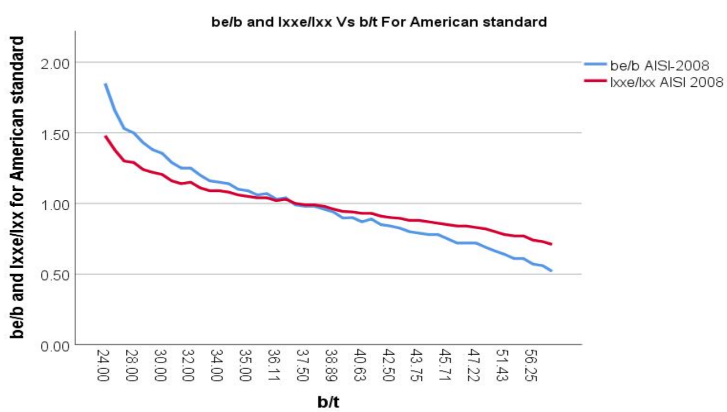


Fig. 10 b/t Versus be/b and Ixxe/Ixx for American code AISI-2008

- Fig. 10 shows that increase in b/t ratio keep the Ixxe/Ixx in the range and get decreases.

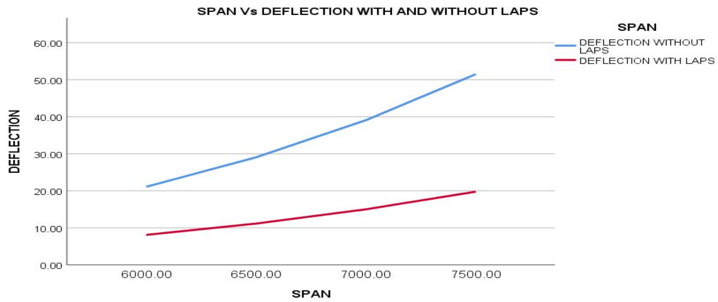


Fig. 11 Span of the purlin Versus Deflection of purlin for Deflection without laps and deflection with laps

- Fig. 11 shows that with increase in the span of the purlin deflection also gets increases. Deflection is greater on the side of without lap purlin.

B. Discussion

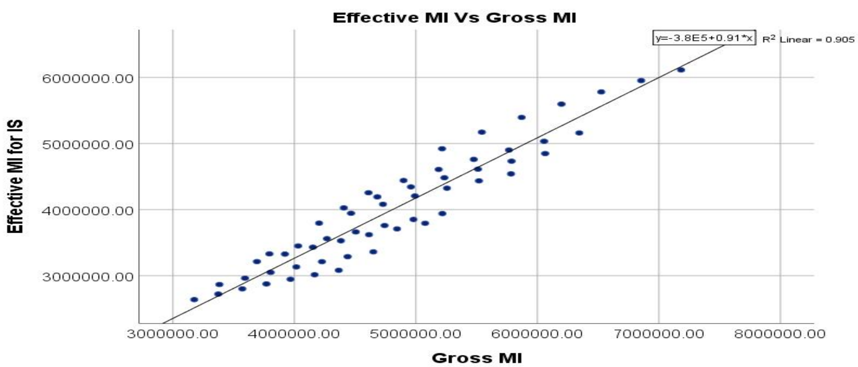


Fig. 6 Gross MI Versus Effective MI for Indian code IS 801-1975

Fig.6 shows the mathematical model for gross moment of inertia versus effective moment of inertia for Indian code and the respected trend line for the results and the formulae derived from that as,

$$\text{Effective MI} = -3.8\text{x}10^5 + 0.91\text{xGross moment of inertia}$$

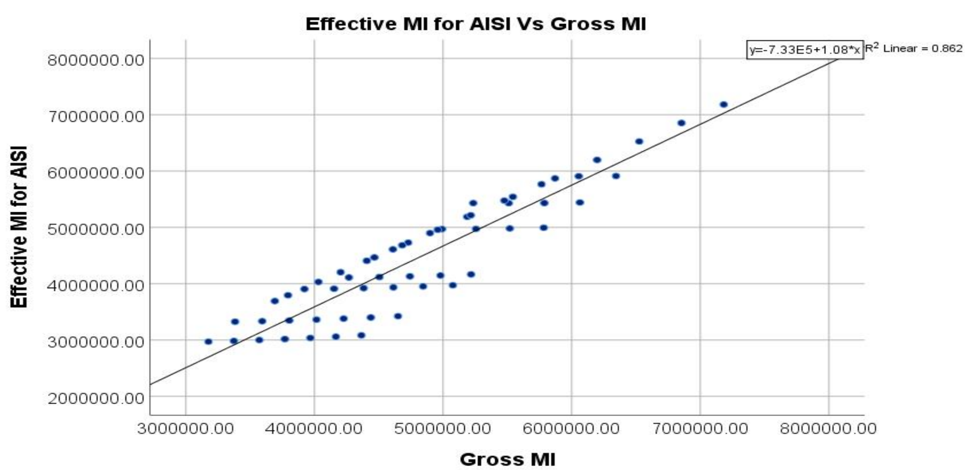


Fig. 6 Gross MI Versus Effective MI for American code IS AISI-2008

Fig.6 shows the mathematical model for gross moment of inertia versus effective moment of inertia for American code and the respected trend line for the results and the formulae derived from that as,

$$\text{Effective MI} = -7.33\text{x}10^5 + 1.08\text{xGross moment of inertia}$$

VI. CONCLUSIONS

1) With the increment in b/t proportion of flange, effective width diminishes, and values calculated by AISI-manual show a variety of around 10% on the higher side.
2) However values of b/t fluctuate from 35 to 60, and the effective moment of inertia also fluctuates by Indian standard,
3) IS 801:(1975) full cross-section of the element isn't used and It is in working stress method (W.S.M.) So updates in the cold-formed structure Indian standard code (IS:801(1975)) is approaching.
4) With overlap, the benefit of doubled cross-section and doubled strength can be achieved. With the installation, if sag rods, approximately, the total deformations are reduced by 50% compared to that of the zee profile without sag rods.
5) End beams are more critical than intermediate ones so we have to design multi-span purlin according to end beams so that we can get safe results.
6) The distribution of deformations along the length of the member is found to be more even with two sag rods as compared to one sag rod.

VII. ACKNOWLEDGMENT

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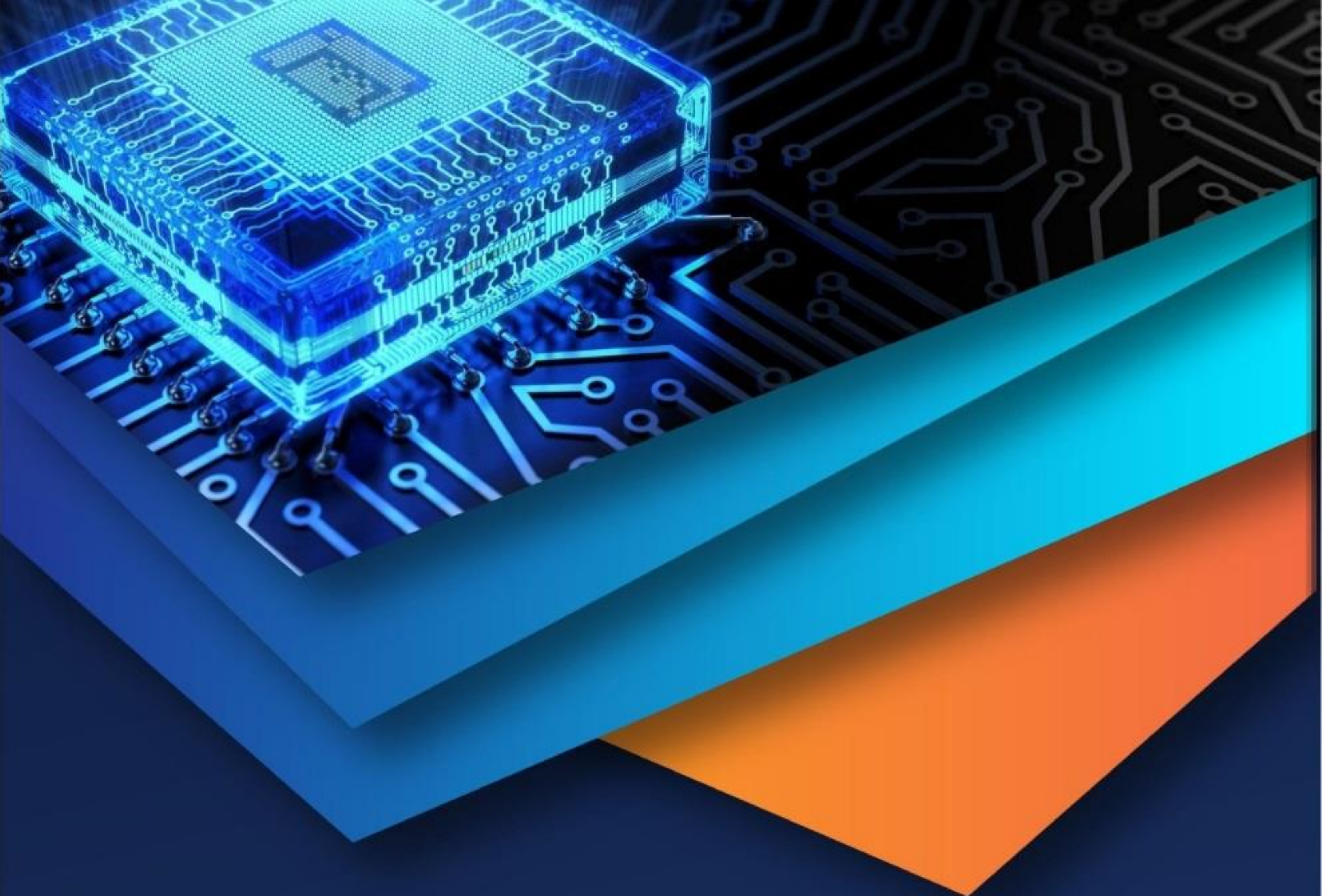

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