Flexural Response of Bolted Lapped Connections in Multi-Span Cold Formed Steel Purlins

Muhammad Bilal Ashraf [1], Faisal Amin[2], Muhammad Ilyas[3] and Azam Khan[4]

[1]MS Scholar, Department of Civil Engineering, FOE, Lahore Leads University, Lahore, Pakistan.

[1]Senior Design Engineer, Design Department, Elite Engineering, Lahore, Pakistan.
[2]Lecturer, Department of Civil Engineering, FOE, Lahore Leads University, Lahore, Pakistan.
[3]Professor, Department of Civil Engineering, FOE, Lahore Leads University, Lahore, Pakistan.
[4]General Manager-Engineering, IZHAR Steel, Lahore, Pakistan.

[1]engr.bilal7777@gmail.com, [2]ilyas@ucest.edu.pk, [3]faisal.amin@ucest.edu.pk, [4]azam.khan@izharsteel.com

Abstract

The In the last 50 years, cold-formed steel structural members such as Z-section purlins have been widely utilized in the metal building construction sector, e.g., pre-engineered buildings. The popularity of these products has risen dramatically in recent years because of their wide applications, low cost, excellent strength-to-weight ratios, and simplicity in fabrication. Plain Z-section purlins are the most common cold-formed steel purlins used for roof systems across the world. Two Z-section purlins are connected so that they function as continuous members of a pre-engineered building with a larger bay span.

The purlins model was made with two spans. Dimension of each span was 8.250m c/c and the spacing between each row of purlin 1.170m c/c, while cleats are used to connect purlins with the supporting beam. For analysis of purlin model, SAP2000 Software was used and found the vertical deflection at intervals (i.e. 0.00mm, 3300mm, 3467mm, 4783mm & 8250mm) under applied loading of 4 increments sequentially. Parallel to the analytical work, an experimental test was also performed to understand the flexural rigidity behaviour of lapped connections over the internal support in multi-span. For experimental work, full-scale two-span purlins were used while the exterior ends were pinned connections while the interior was lapped connections, and the vertical deflections were measured at the same intervals mentioned above by using SOKIA Auto Level-B20, under applied loading at intervals of 4 increments. Comparisons were made between vertical deflections obtained from analysis using SAP2000 software, experiments, and code IBC-2009.

Keywords: *Cold-formed section, Lapped connection, Z purlin, flexural rigidity, vertical deflection, SAP2000, Applied loading in 4 increments, IBC-2009*

1. Introduction

Cold-formed members are the replacement to traditional buildings members such as hot rolled profiles. The cold-formed steel is commonly use as purlin in industrial structures such as pre-engineered buildings. Purlins are secondary members (as shown in Figure 1.1) that support and sustain the sheeting against gravity and wind load. It is well known that when continuous purlins are used to replace simply supported purlins for a long length member via intermediate supports, the best results are obtained for a simply supported purlin for a long length member via intermediate supports, because the maximum bending moment at mid span for such simply supported purlins is reduced due to the negative end moment.

Continuity of purlins can be achieved by choosing connection configuration which determines the moment transfer between members; therefore, special attention must be paid to the connection between individual purlins. The most common methods for joining two lapped purlins at the support is use of bolted connections. Lapped connections were considered to have the same flexural stiffness and moment resistance as single sections or the total of the two sections joining at the lapped portions. In addition to the flexural rigidity and moment resistance of the lapped connections over the internal support would not only affect load carrying capacities of purlin but also the vertical deflections and moment distribution of multi span purlin systems (see below Figure 2.1).

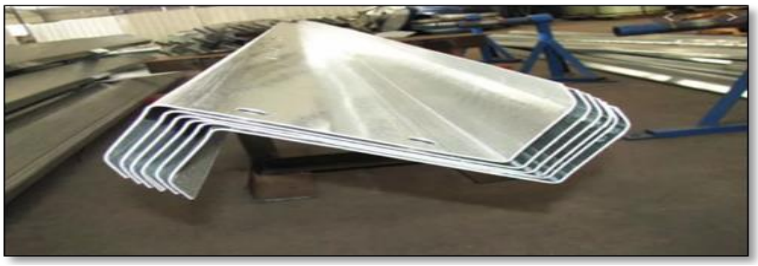


Figure 1.1 Purlin

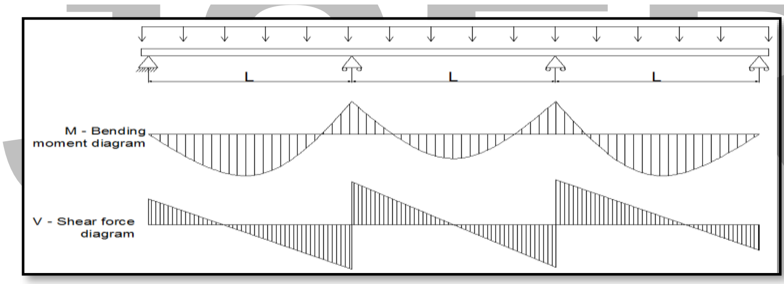


Figure 1.2 Multi-span purlin system

1.1 Objectives

Z-Section purlins are commonly used in pre-engineered structures because they have the advantage of being lapped at support locations and nested together to increase stiffness.

- This capability increases the structure's strength and reduces deflections.
- To determining the serviceability capacity of lapped connections by using Z-Section purlin having same depth and thickness.
- To evaluate the impact of deflection under two conditions: i.e., ‘full continuity” and “no continuity”.
- To compare the software results of deflection with experimental results.

2. Literature Review

Research on Structural Behavior of Lapped Connections:

Kavya.E1 , Swedha .T2 (2017) For test overlap purlins or short sleeve member are bolted that held and connected to the purlins are used. (See Figure 2.1). The purpose of this work is to determine the capacities of sleeved connections and bolted overlapping for sigma and Z- sections with the same thickness and depth. Finite element analysis is used to measure load bearing capability, stability and failure modes for the four separate connections.

The investigation indicates that overlapped connections of both Z and sigma sections had higher capacity than sleeved connections but overlapped Z-section and sleeved connections failed due to distortional buckling while sigma section overlapped are failed due to flexure-torsional buckling. When a sleeved and overlapped connection are compared, the lapped connection is more efficient than the sleeved one.

Pham, Emmett and Davis (2014), In two series high strength lapped cold-formed steel Z-purlins with bolted connections are evaluated along combined bending and shear in both numerical and experimental. A single Z purlin section was chosen, with unequal bottom and top flange thicknesses and widths. All section failures occurred just outside the end of laps and then were caused by a combination of shear and bending at the critical areas, according to the results. In testing without straps significant cross-section deformation was observed at the end lap, resulting in lapped connection discontinuity and a considerable decrease in the flexural strength of lapped purlins. The continuity of the lapped connection was improved in strap tests, and there was no visible deformation in the cross-section. The flexural strength of lapped purlins was significantly increased as shown in Figure 2.1.

Ungureanu and Dubina (2010), Numerical analysis was done on lapping cold-formed Z- section purlins with the bolted connections. The purlins were found to be semi-continuous at the intersection of the lapped portions according to the authors. On the edge of lap section were found to be the critical section, however combined bending and web crippling caused by the bolts in flange and bearing fastening governed the load carrying capacity of lapped purlins.

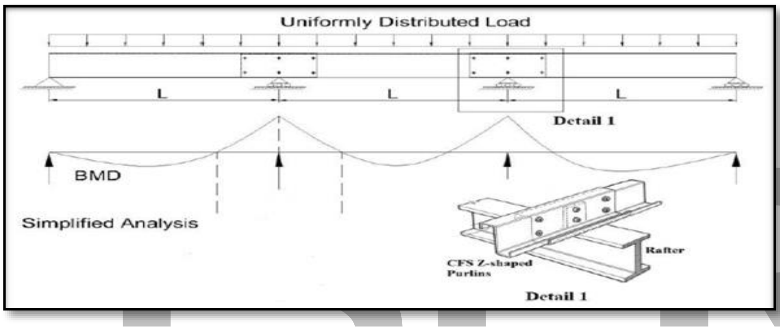


Figure 2.1 Multi span CFS Z-shaped Purlin system

Zhang and Tong (2007), investigated the multi-span purlin systems, flexural stiffness and moment resistance of lapped connections. As shown in Figure 2.2, two connection setups were used, self-drilling screws and web bolts at top flange only or at both flanges. For all tests, a standard stiffened Z-section was utilized, with different bottom and top flange widths.

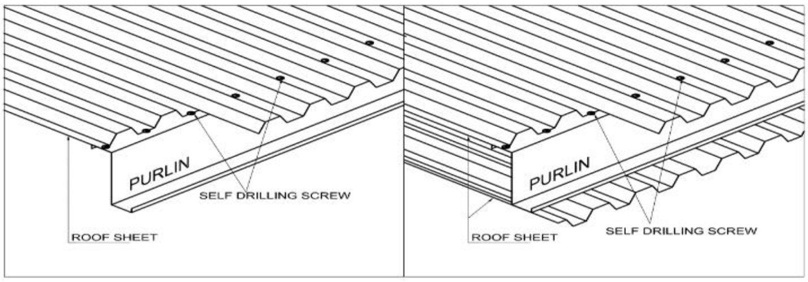


Figure 2.2 Typical Roof System

Results showed that the bending moment dominates the load-carrying capacity of lapped connections that have been tested, while the most critical section of lapped purlins is edge section of the lapped connection. At internal support sections have approximately double the moment resistance of edge section of lapped connection.

Chung and Ho (2005), they provided a systematic approach to analyses all internal forces in lapping connections and along individual components. Towards the critical cross-section of the lapped connections at the end of the lap. The researchers concluded that, due to the highly confined shear buckling mode shape, the shear capacity of the critical cross section may be improved by reducing the length of the shear panel. Design requirements were developed by examining the combined bending and shear at the crucial cross-section at the conclusion of the lap. In addition, the minimum and maximum effective flexural rigidity of the Z-section lapped were calculated using design formulae. [10]

3. Methodology and Experimental Setup:

Cold-formed Z-Section purlins are used as secondary flexural members. These members are spliced at the supporting rafters by employing a lapped joint. Two rows of purlins, each having two spans of 8.250m c/c and spacing between each row of purlin is 1.170m c/c are considered. Width of roof sheet used is 1.220m and connected with top flanges of purlins using screws. Parallel to this experimental work (see Figure 3.4), Analysis of purlins are performed on SAP2000 software and obtained vertical deflection under applied loading in 4 increments. Comparison has been made between experimental and software results.

3.1 Overlapped connection:

In this type of connection, purlins are given an extra length known as overlapping length, which is lapped with adjacent purlins and fastened together. To maintain continuity over the whole length of the building. The distance between the centers of the edge bolts is measured as lap length (see Figure 3-1). The length of a purlin connection is determined by factors such as the beam's span and the depth of the purlin section.

3.2 Sheeting:

In purlin load test 0.50mmthick S-Profile sheet is used with specification and dimensions are mentioned below in table 3.1 and figure 3.2 to carry the load.

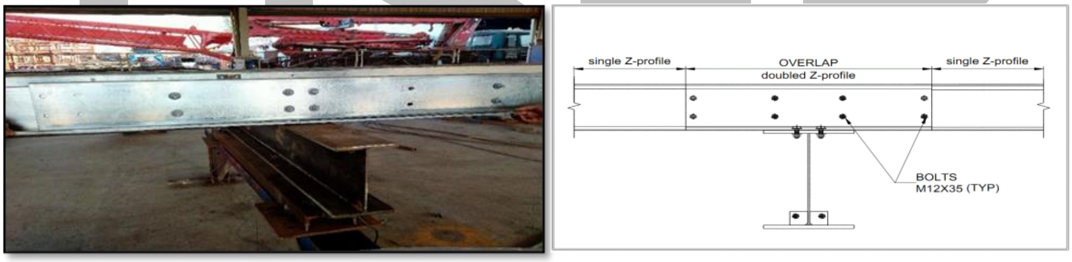


Figure 3.1 Lapped Connection

Table 3.1 Material/mechanical Specifications of sheeting

Structural Components	**Sheeting Panels (AluZinc coated steel Pre-painted)**
Specifications	ASTM A792M Grade 345 Class 1 Coating: AZ150
F_y=Yield Strength (Ksi)	F_y =50

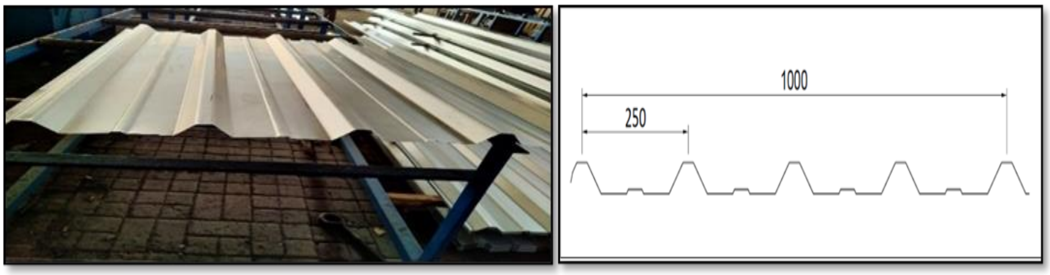


Figure 3.2 S-Profile Sheeting

3.3Mechanical Properties and Section Properties of Z shaped Purlin:

The mechanical characteristics of CFS (cold-formed steel) Z-shaped purlins are evaluated using ASTM standard E8 tensile coupon tests (ASTM, 2011). The section parameters were calculated using the AISI S100 North American Specification for the Design of Cold-Formed Steel Structural Members (AISI 2012).

3.3.1 Section properties

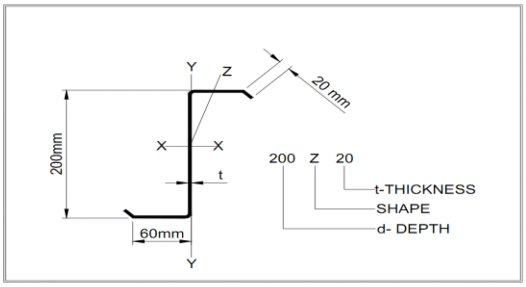


Figure 3.3 Z-section geometry

Table 3.2 Z-section geometrical Properties

Section	**200Z20**	
Weight	kg/m	5.5
Thickness (t)	mm	2.0
Area	cm^2	6.9
Effect. Area	cm^2	6.7

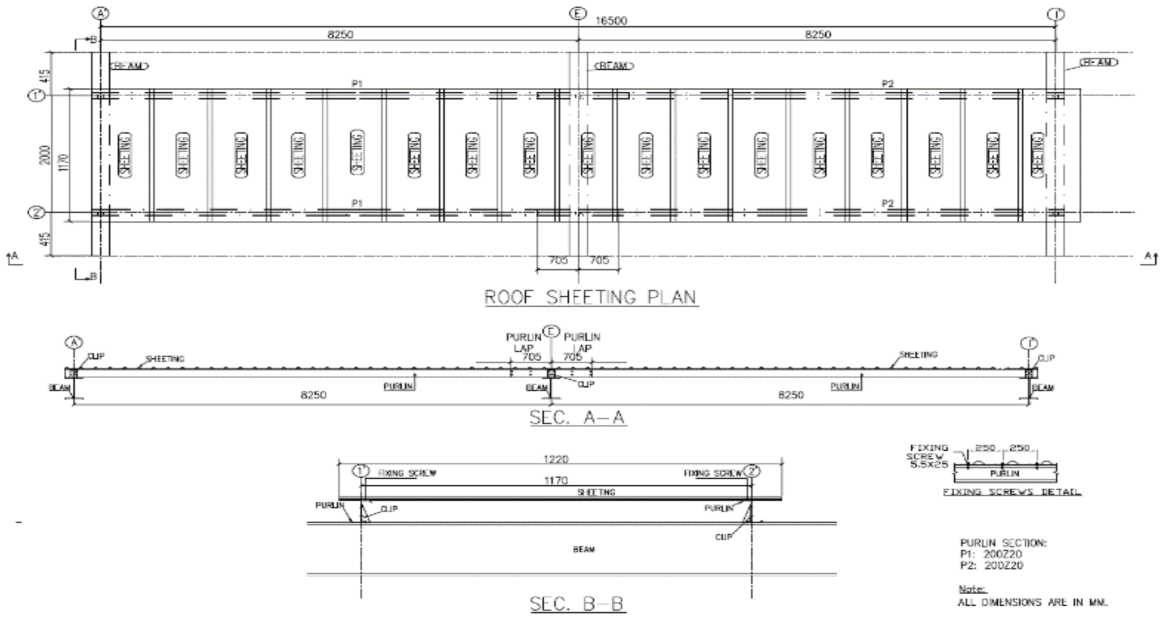
Table 3.3 Material specifications and strength of cold formed secondary members

Structural Components	**Cold Formed Steel**
Specifications	ASTM -A653m Sq 50 Class- 1 (Galvanized)
F_y=Yield Strength (KSI)	F_y =50

Table 3.3 Section Properties of Z-purlin

Section	**200Z20**		
Properties about X-Axis	I_x	cm^4	409.1
	Gross S_x	cm^3	40.9
	Effect. S_x	cm^3	38.5
	R_x	cm	7.7
Properties about Y-Axis	I_y	cm^4	57.3
	S_y	cm^3	8.1
	R_y	cm	2.9
I_{xy}		cm^4	111.2
R_{min}		cm	1.9

3.4 Layout scheme



3.5 Calculation of Loading:

The mechanical characteristics of CFS (cold-formed steel) Z-shaped purlins are evaluated using ASTM standard E8 tensile coupon tests.

- Dead/Self Weight of purlin 200Z20 = 5.65kg/m= 0.055 KN/m^2
- Dead/Self Weight of 0.50mm thick (S-Profile) sheeting = 4.17 kg/m^2
    - Total Length of sheeting = 16500mm
    - Total Width of sheeting = 1220mm
- Half load of sheeting will distribute on one side and half will be on another side

So, Dead/Self Weight of 0.50mm thick (S-Profile) sheeting on one side

$$= \frac{1220}{2x1000} \times 4.17 \times \frac{9.81}{1000} = 0.025KN/m$$

3.5.1 Live Load:

Total applied load of 5724kg is applied with 4 increments as follow:

- Total 1st step loading = 27×12(plate) + 27×50(cement bag) =1674kg
- 1st step loading on one side = $\frac{1674}{2x16.50} \times \frac{9.81}{1000} = 0.50KN/m$
- 2nd step loading = 1674 + 27×50(cement bag) = 3024kg
- 2nd step loading on one side = $\frac{3024}{2x16.50} \times \frac{9.81}{1000} = 0.91KN/m$
- 3rd step loading= 3024 + 27×50(cement bag) = 4374kg,
- 3rd step loading on one side = $\frac{4374}{2x16.50} \times \frac{9.81}{1000} =1.30\ KN/m$
- 4th step loading = 4374 + 27×50(cement bag) = 5724kg,

- 4th step loading on one side = $\frac{5724}{2x16.50} \times \frac{9.81}{1000} = = 1.70KN/m$

3.6 Applying loading

Figure 3.4 Application of (a) self-weight, (b) 1ststep loading, (c) 2nd step loading, (d) 3rd step loading, (e) 4th step loading (Experiment)

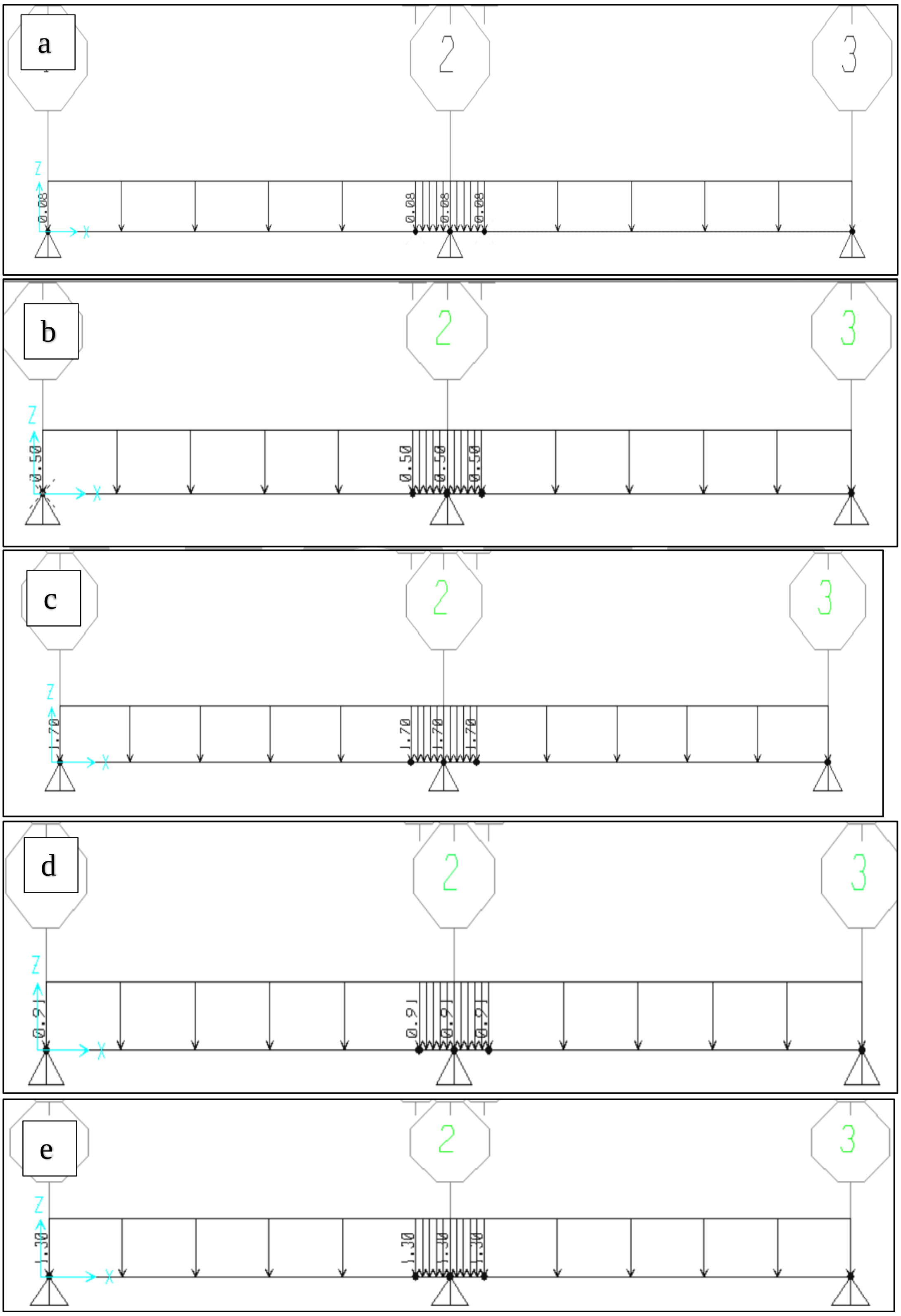


Figure 3.5 Application of (a) self-weight, (b) 1ststep loading, (c) 2nd step loading, (d) 3rd step loading, (e) 4th step loading (SAP2000 Software)

4. Results

Two Z-section purlins are connected (as describe in Figure 2.1) in such a way that they function as continuous members. The research has been carried out using lapped connections. Vertical deflections are obtained at intervals as shown in Figure 4.1 by using SAP200 Software and by experiment.

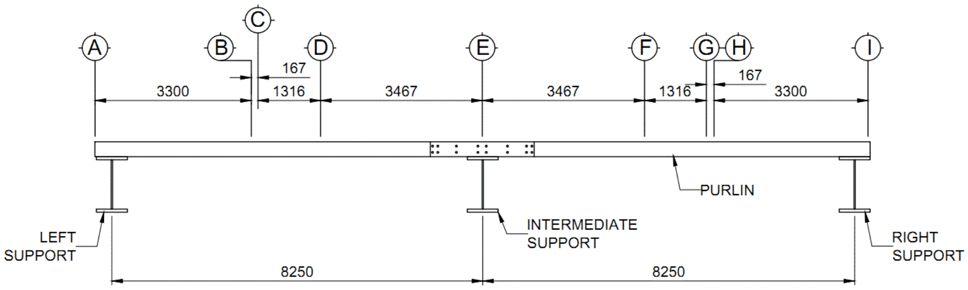


Figure 4.1 Scheme of lapped purlin

4.1 Code maximum allowable deflection limit (IBC-2009- Table 1604.3)

Span = L =8250 mm

Allowable limit = Span/120 =L/120 = 8250/120 = 68.75 mm

4.2 Experimental Results

Vertical deflections have been calculated on each point as mentioned in Figure 4.1. Table 4.1 shows the results.

Table 4.1 Vertical Deflection Results (Experimental)

	Distance	**A=0.00mm (Left support)**	**B=3300 mm**	**C=3467 mm**	**D=4783 mm**	**E=8250 mm (Middle support)**	**F=11717mm**	**G=13033mm**	**H=13200mm**	**I=16500 mm (Right support)**
Vertical Deflection	**1st step loading**	0	14	14	12	0	12	13	14	0
	2nd step loading	0	25	24	23	0	23	24	25	0
	3rd step loading	0	37	36	34	0	32	35	36	0
	4th step loading	0	48	47	42	0	40	47	48	0

4.3 SAP2000 Software Results

Vertical deflections have been calculated on each point as mentioned in Figure 4.1. Table 4.1 summarizes the findings.

Table 4.1 Vertical Deflection Results (SAP2000 Software)

Distance		A=0.00mm (Left support)	B=3300 mm	C=3467 mm	D=4783 mm	E=8250 mm (Middle support)	F=11717mm	G=13033mm	H=13200mm	I=16500 mm (Right support)
Vertical Deflection	**1st step loading**	0	14.64	14.54	11.72	0	11.72	14.54	14.64	0
	2nd step loading	0	25.02	24.85	20.03	0	20.03	24.85	25.02	0
	3rd step loading	0	35.01	34.78	28.06	0	28.06	34.78	35.01	0
	4th step loading	0	45.19	44.89	36.18	0	36.18	44.89	45.19	0

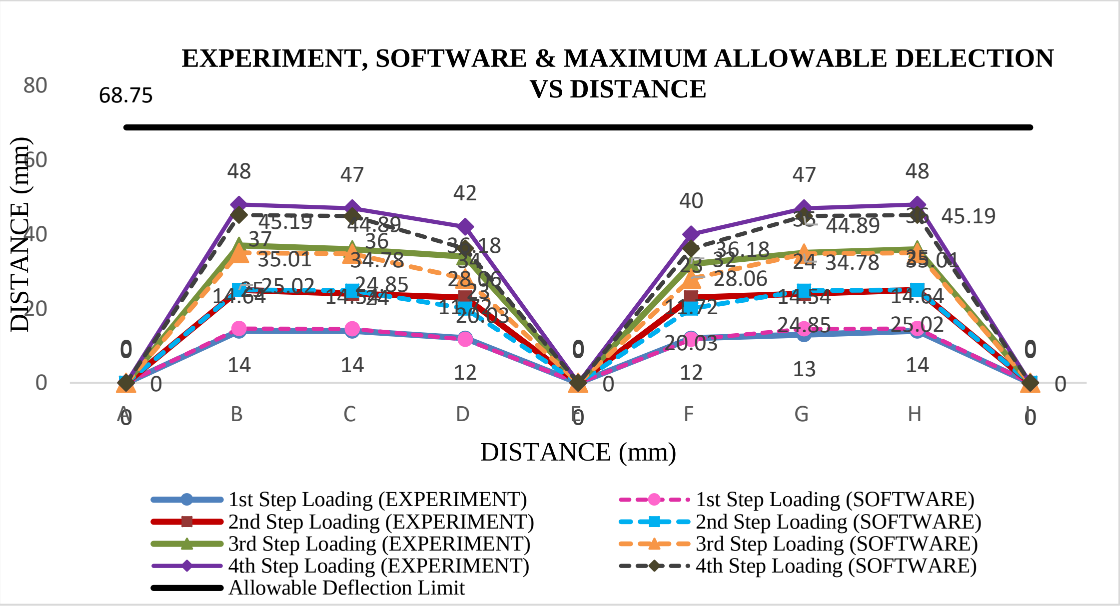


Figure 4.4 Combined loading (Experimental &Software) vs. Code maximum allowable limit

4.4 Maximum theoretical vertical deflection for multi-span purlin with "full continuity" at support:

Total Self weight from section 3.7.5 i.e., 0.08KN/m (See section 3.5)

Live load from section 3.7.5.1 i.e., 1.70KN/m (See section 3.5.1)

Total Load = 0.08+1.70 = 1.78 KN/m

E= modulus of elasticity of steel = 20000000KN/m^2 (See Table 3.3)

I= Moment of Inertia = 409.1cm4 = 0.0000040910m4 (See Table 3.3)

Maximum Vertical Deflection for “full continuity” = $(\Delta_v) = \frac{1}{185} \times \frac{wl^4}{EI}$

$$(\Delta_v) = \frac{1}{185} \times \frac{1.78\times 8.250^4}{200000000\times 0.0000040910} = 0.0544m \text{ =54.47mm}$$

4.5 Maximum theoretical vertical deflection for multi-span purlin with “no continuity” at support:

Total Self weight from section 3.7.5 i.e., 0.08KN/m (See section 3.7.5)

Live load from section 3.7.5.1 i.e., 1.70KN/m (See section 3.7.5.1)

Total Load = 0.08+1.70 = 1.78 KN/m

E= modulus of elasticity of steel = 20000000KN/m2 (See Table 3.3)

I= Moment of Inertia = 409.1cm4 = 0.0000040910m4 (See Table 3.3)

Maximum Vertical Deflection for “no continuity” = $(\Delta_v) = \frac{5}{384} \times \frac{wl^4}{EI}$

$$(\Delta_v) = \frac{5}{385} \times \frac{1.78\times 8.250^4}{200000000\times 0.0000040910} = 0.13m \text{ = 130mm}$$

5.0 Conclusion

The following conclusions are drawn, and observation made from the study on “Flexure behaviour of bolted lapped connections in multi-span steel Z-section purlin”.

1. The maximum theoretical vertical deflection is formed 130mm in multi-pan purlin with no continuity at support.
2. Results of maximum vertical deflection under theoretical, SAP2000 software and experiments are similar (i.e., 45.47mm, 45.19mm, and 48mm, respectively) in multi-span purlins with full continuity at support.
3. The comparison of theoretical results with no continuity to full continuity shows an increase of almost 2.8 times. Whereas the experimental results and the results obtained using the SAP2000 software were found to be almost similar. So, two-span purlins with lap are behaving as continuous beams.
4. Comparing the results of no continuity and experimental results clearly demonstrate that full continuity is achieved. Without continuity at lap, the maximum vertical deflection of 48mm cannot be achieved.
5. The strength of support within the lapping zone is the sum of the strength of the two Z-section purlins, and lapped connections improve the load-bearing capacity of Z-section purlins.

5.1 Future Recommendations:

This work was first step to explore the behavior of bolted purlin lapped connections by using SAP2000 software and experimental work. The next step should be:

1. Experimental results can be used as baseline for multispan Z-section purlins, and lap connections can be considered as fully rigid connections.

2. For this research work, we have studied the behavior of lapped connections under uniformly distributed load (UDL). The behavior of lapped connections can also be studied under point load.

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