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STRUCTURAL BEHAVIOR OF COLD FORMED C SECTIONS WITH BOLTED LAPPED CONNECTIONS

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ABSTRACT

Cold-formed steel built-up sections are commonly used as compression elements to carry larger loads and longer spans when a single individual section is insufficient. For such cases lapping of two sections at the interior support is done to maintain the continuity of the beams. Connections are an important aspect of such structures since structural behavior, and hence economy, is dictated to a large extent by the behavior of the connections. There are numerous types of fastenings between cold formed steel components. However, where holes are punched during forming, bolts are by far the most common type of fastener used in practice. This paper describes about the structural behaviors like buckling modes, maximum load carrying capacity and other possible modes of failure of the whole members under static loading at the lapped area. Two separate beams are taken and lapped with bolts to form a single continuous beam. The two lapped cross sectional C-shaped sections are made with varying cross sectional area. Totally three beams with lapping distance varied between them are tested. Finally the experimental results are compared with numerical analysis using ANSYS.

Keywords: Lapping, structural behavior, bolted connection, buckling etc.

1. INTRODUCTION

Cold form sections are light weight building materials with the maximum thickness of about 3.00 mm [1]. They have high strength to self weight ratio and are suitable for construction due to their flexibility in applications, need minimal maintenance due to the red oxide coating, lifting can be done without any heavy cranes and ease of fabrication. They are manufactured into various shapes by roll forming and therefore special considerations needed. The materials having yield strength of 280, 350 and 450 N/mm are available commonly. High strength cold formed steel sections are usually used in wide range of applications which include lipped C and Z sections in roof systems [2]. Since the usage of a

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single section is insufficient in roofing of buildings, lapping of two sections comes into existence [3]. For a lapped section one has to use the DSM (Direct Strength Method) to study the buckling. For a continuous beam high bending and shear can act simultaneously at support points [4].

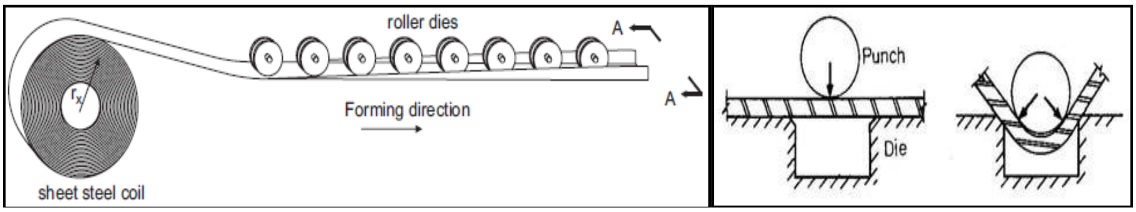


Figure 1. Forming methods for cold-formed steel members (a) Cold rolling (Moen et al., 2008) (b) Press-braking (Yu, 2000)

The behavior of cold formed sections and hot rolled sections diverge where the thin walled structural elements buckle locally on the application of compressive load. Therefore cold-formed cross-sections are generally classified as slender sections because the amount of material in cross-section will undergo premature buckling failure and hence they cannot generally reach their full strength [5].

The cold-formed members are also susceptible to distortional buckling and lateral-torsional buckling because the cold-formed member gives low torsional rigidity and at the same time gives great flexural rigidity about one axis. It gives low flexural rigidity about a perpendicular axis which is because of their open, thin, cross-sectional geometry

2. SCOPE

To provide a perceptive on the structural performance of lapped connections between cold-formed steel C sections, which are used for multi-span purlin systems with overlaps in modern roof construction.

3. USAGE OF CUFSM

A CUFSM (Cornell University Finite Strip Method) solution provides an approach for stability solutions to be focused for a given buckling mode (*modal decomposition*). CUFSM is an open source FSM program. For stability analysis and to get the section properties of cold-formed steel members the conventional and constrained finite strip methods are implemented in the program CUFSM**.** Conventional FSM provides a means to examine all the possible instabilities in a cold-formed steel member under longitudinal stresses (axial, bending, or combinations thereof). The basic framework of the FSM stability solution will be familiar to anyone who has studied matrix structural analysis. Thus one can employ DSM (Direct Strength Method) approach.

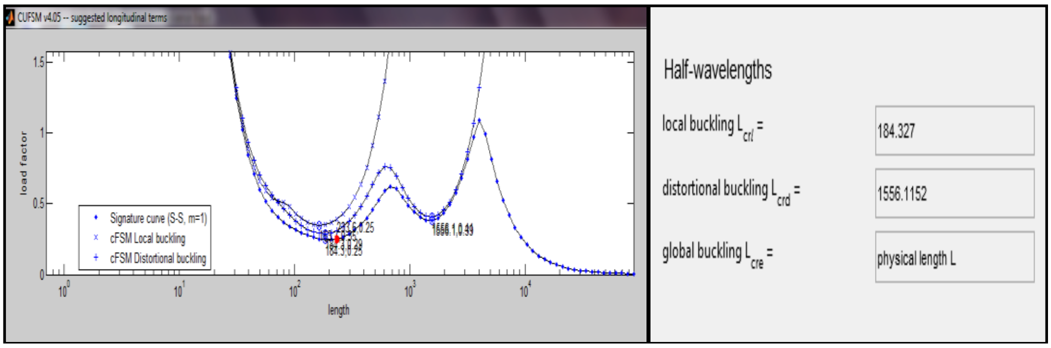


Figure 2. (a) Graph showing local buckling and distortional buckling from CUFSM (b) Values of local and distortional buckling

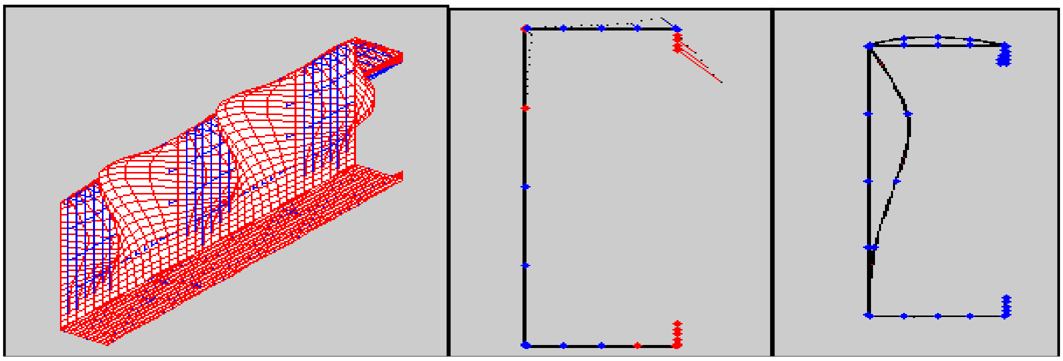


Figure 3. (a) 3-D Buckling shape of a single beam. (b) Out plane buckling shape. (c) In plane buckling shape

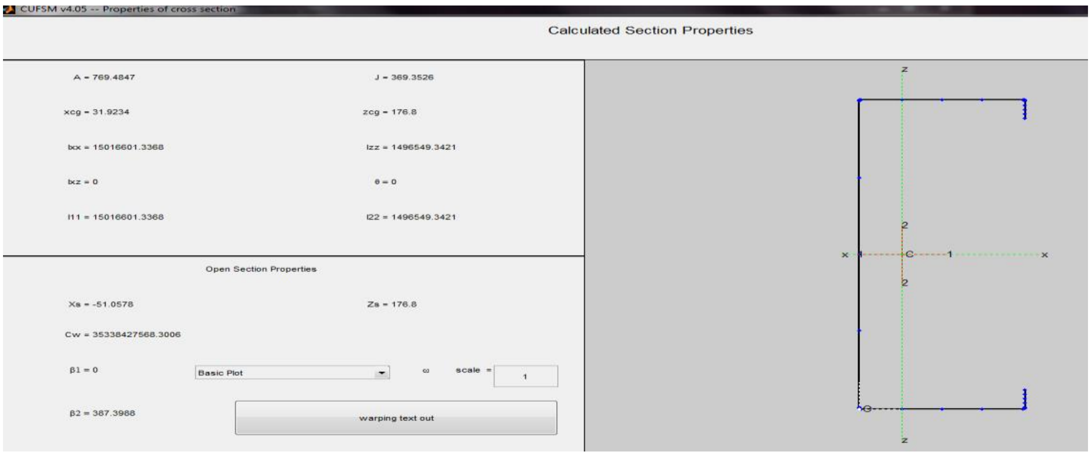


Figure 4. Calculated section properties from cufsm

4. TEST PROGRAM

4.1 Coupon test

To find the parameters of steel such as tensile strength and stiffness, coupon test are widely recognized as a standards. Tensile testing utilizes steel made of standard coupon test geometry as shown. It consists of two regions, central part and two end regions where the failure is expected to occur in the central part. The end regions are clamped to the test machine.

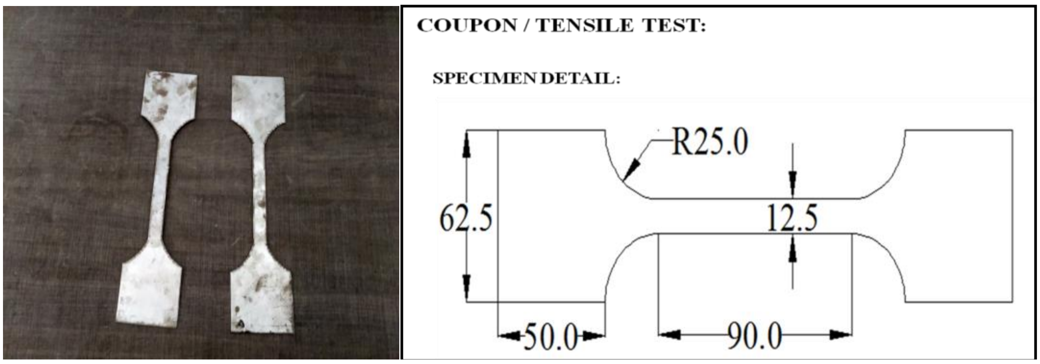
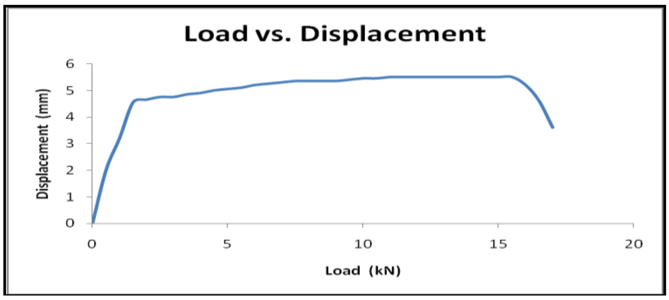


Figure 5. (a) Coupon test specimens (b) Standard dimensions for coupon test

The specimen is tested in the universal testing machine and the obtained corresponding values are listed below

Table 1: Values obtained from coupon test

Maximum Force (F_m)	5.550 kN	Yield load	1.950 kN
Displacement at F_m	12.730 mm	Yield stress	0.0021 kN/mm^2
Maximum Displacement	17.280 mm	Tensile Strength	0.005 kN/mm^2
C/S Area	1125 mm^2	Elongation	19.2 %



Graph 1. Load vs. Displacement

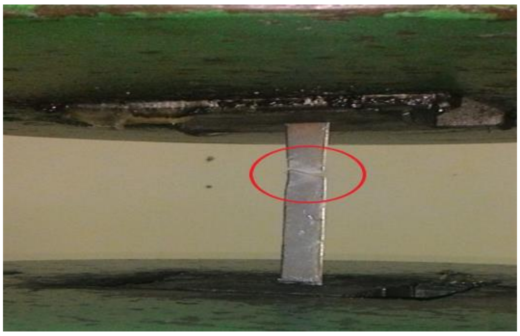


Figure 6 Failure of specimen

4.2 Modeling of lapped beams using autocad

The models are created using the exact dimensions in this software shown below in the table, such that it can be used for Fabrication purposes.

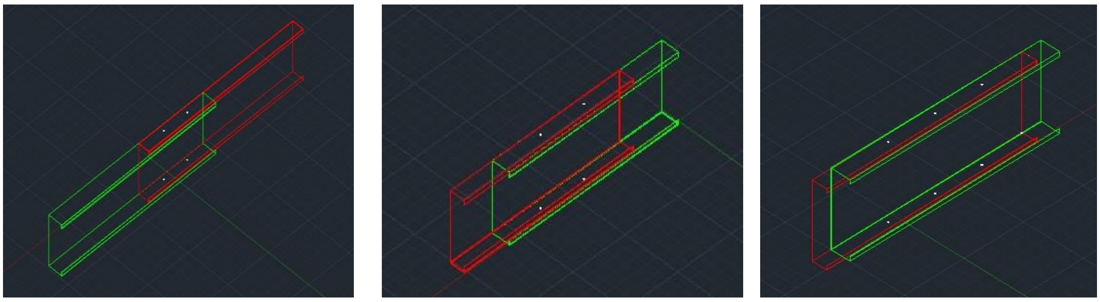


Figure 7. (a) 500mm lap between two sections (b) 750mm lap between two sections (c) 900mm lap between two sections

Table 2: Section Dimensions and respective lap distances

SECTION	HEIGHT (mm)	WIDTH (mm)	LIP (mm)	THICK (mm)	LAPPING DISTANCE (mm)
C 247	247	80	18	1.2	600
C 250	250	100	20	1.2	
C 297	297	80	18	1.2	750
C 300	300	100	20	1.2	
C 347	347	80	18	1.2	900
C 350	350	100	18	1.2	

The section dimensions, bolts and the corresponding lapping distances between each section were selected according to the previous research papers and the selected sections were checked with CUFSM software as a single beam for stability conditions.

The smaller section is made with flange width 20 mm less than larger section instead of the exact reduction of thickness of 1.2mm of flange width. Such a way one can induce torsion capacity in the sections during testing.

4.3 Fabricated beams

Figure 8. (a) Lapping distance: 500 mm (b) lapping distance: 750mm
(C) Lapping distance: 900mm

4.4 Loading of beams

4.4.1 Two point loading

The beams which are lapped with bolts are tested under loading Frame at a distance of 1/3 of the beam. The given rate of loading per minute is 5kN. The loading is given as a two point loading.

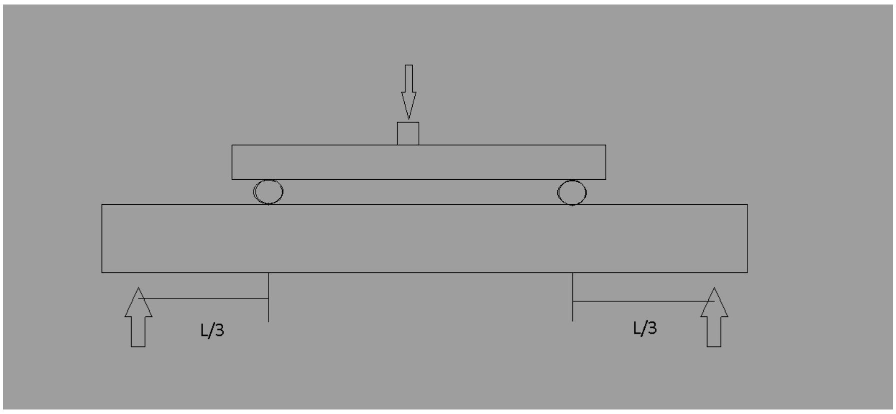


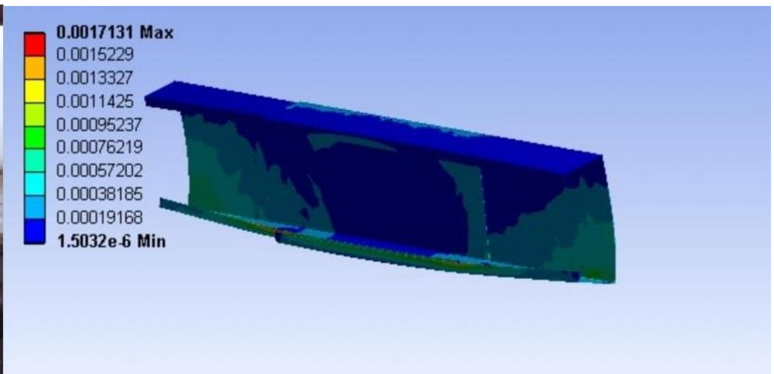
Figure 9. Two point loading experimental setup

4.4.2 Finite Element Analysis

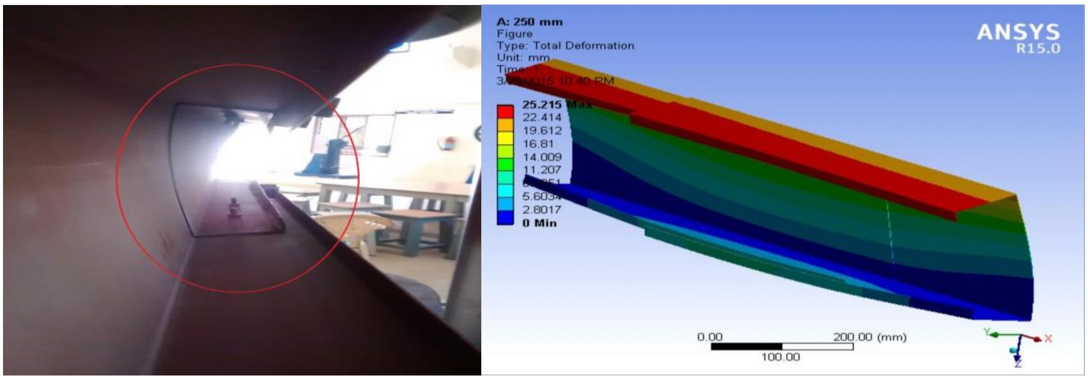
In all finite element analysis, a real structure is idealized to a (finite) number of 'elements' – hence the name. Stiffness matrix equations are formed and solved to ensure equilibrium between the elements, the applied loads and the structural supports. The resulting displacement matrix can be used to back-calculate forces, moments and stresses for use in design.

4.5 Results and discussion

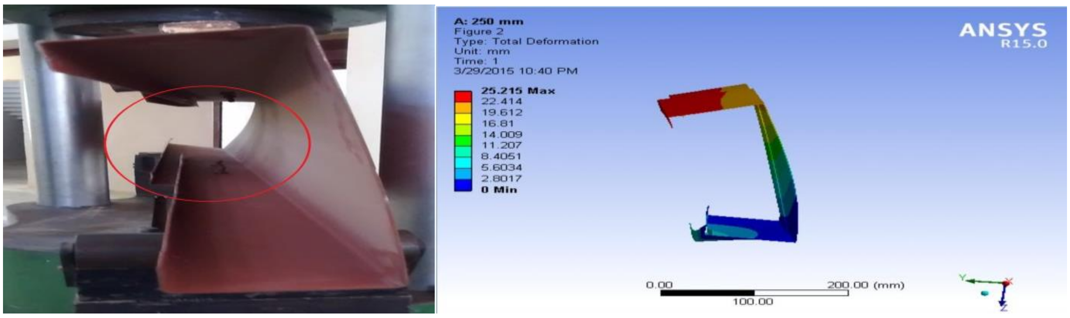
4.5.1 Modes of buckling



Local buckling

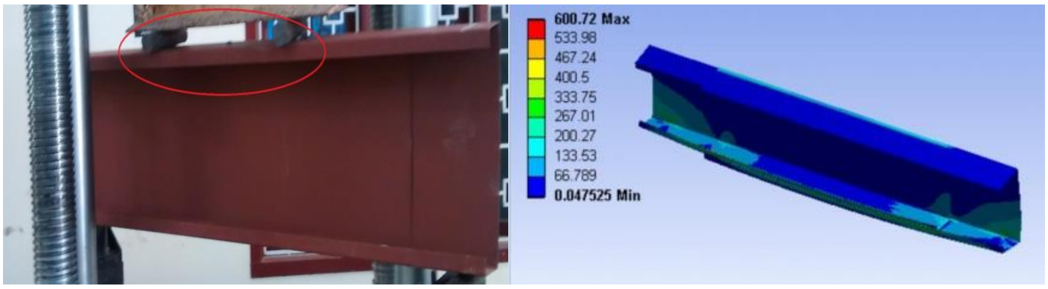


Distortional buckling

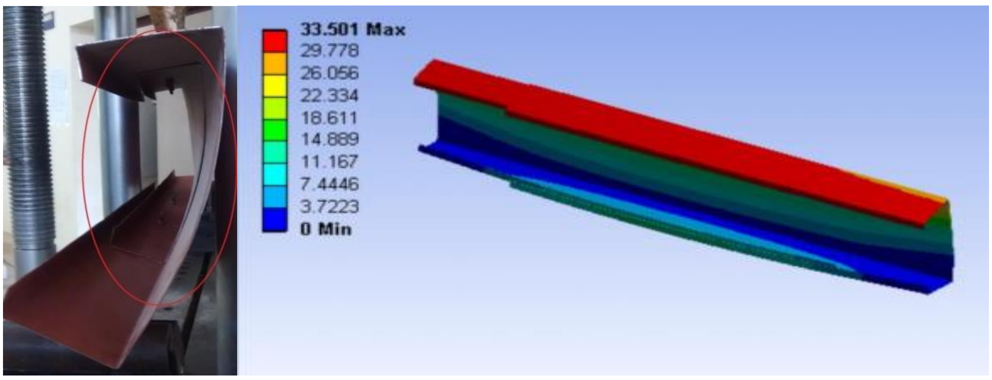


Lateral Torsional buckling

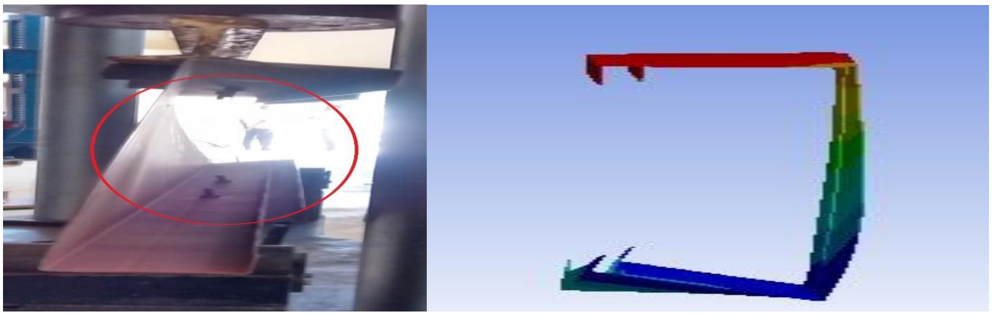
Figure 10. Buckling for 600 mm lapped sections



Local buckling



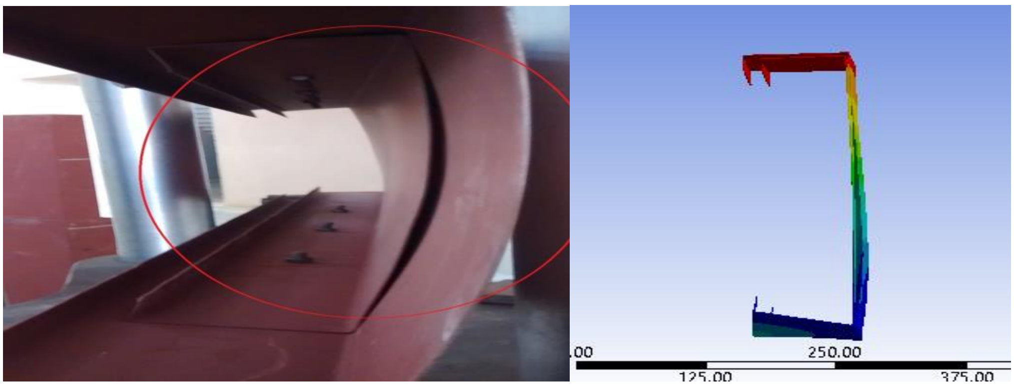
Distortional



Lateral Torsional buckling

Figure 11. Buckling for 750 mm lapped sections

Local buckling

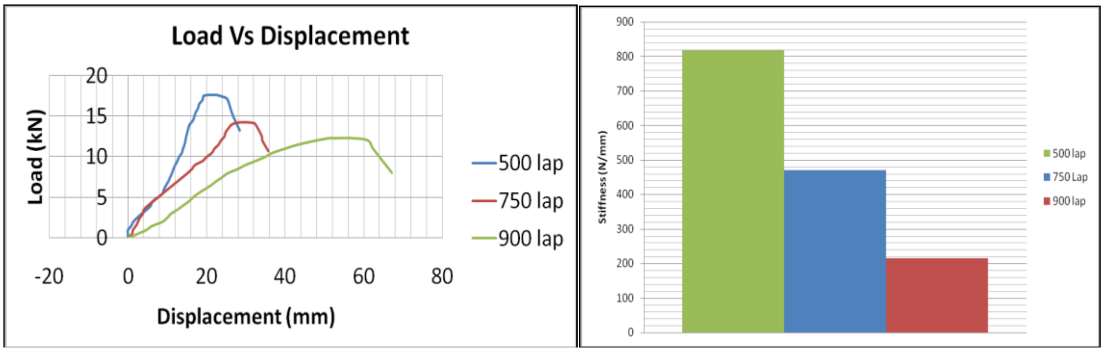


Distortional buckling

Figure 12. Buckling for 900 mm lapped sections

Three built up beams of different dimensions and different lapping distances between them are tested in the loading frame to find the buckling modes produced by each member. The Section properties and the tensile strength of the material are given in Table 1 and 2 respectively. The section with 500mm lap between them has local buckling where the flange at the compression side alone has buckled as shown above. It also has distortional buckling where the whole cross section changes due to buckling. The reduction of flange width between the built up sections causes lateral torsional buckling where the whole member got twisted in the opposite direction. The lapping of two beams gives an increased thickness at the support areas and also reduces the amount of failure due to lateral torsional buckling.

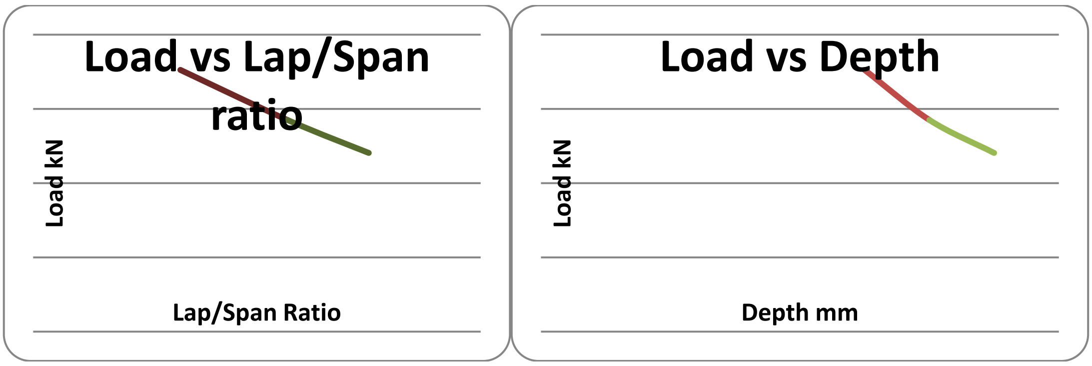
The 750mm lapped section is also similar to that of the above section where the same three buckling exists. The section with 900mm lapping distance produces only two buckling local and distortional. For this section there is no visible torsional buckling as a result of the increased lapped area. After the removal of loads all the beams regained their original shape which indicates that the failure of built up sections will not be sudden.



Graph 2. (a) Load Vs Displacement (b) Stiffness of the Sections

From the load-displacement graph, the maximum load carrying capacity decreases as the depth of the section increases even though the lapped area is more for the section with maximum depth.

From the Stiffness graph, it is found that the stiffness of the sections depends on the height of the section. The lapping of two sections increases the stiffness by very small amount but it is still not as good as using separate stiffeners (Stiffeners result from literature).



Graph 3. (a) Load vs. Lap/span Ratio (b) Load vs. Depth

From the graph, the loading amount decreases with respect to both depth and Lap/span ratio. From previous literature results the lap/span ratio of 0.6 should have maximum load but the depth is more for that section which produces maximum buckling thereby reducing the load value.

4.6 Conclusions and recommendations

Based on the findings of this study, the following conclusions were drawn.

- The increase in the lapping distances of two sections reduces the lateral torsional buckling of the whole section which consecutively reduces the risk of sudden rupture of the member.

- The maximum load carrying capacity increases for the section with minimum height and the deflection amount increases for the section with maximum height regardless of the increase in lap distances.
- The stiffness of the member decreases with the increase in the height of the section which proves that lapping of section only increases the thickness at the critical area(at the end of lap connection). Therefore separate stiffeners are provided to increase the stiffness.
- Further study in the built up sections with same depth and varying lap distances would provide effect of lapping and the role of dimensions of the sections.

Consideration of bolt moment capacity in further study can be made for the influence of bolts in the load carrying capacity of lapped members.

REFERENCES

1. Chung KF, Ho HC. Experimental investigation into the structural behaviour of lapped connections between cold-formed steel Z sections, *Thin Walled Structures*, **42**(2004) 1013-33.
2. Zhang L, Tong G. Moment resistance and flexural rigidity of lapped connections in multi span cold formed Z purlin systems, *Thin Walled Structures*, **46**(2008) 551-60.
3. Dubina D, Ungureanu V. Behavior of multi span cold formed Z-purlins with bolted lapped connections, *Thin Walled Structures*, **48**(2010) 866-71.
4. Pham CH, Gregory Hancock J. Experimental investigation of high strength cold formed C-sections in combined bending and shear, *Journal of Structural Engineering, ASCE*, **136**(2010) 866-78.
5. Cheng Yu, Benjamin Schafer W. Distortional buckling tests on cold formed steel beams, *Journal of Structural Engineering, ASCE*, **132**(2006) 515-28.
6. Schafer BW. The Direct Strength Method of cold- formed steel member design, *Journal of Construction Steel Research*, **64**(2008) 766-78.
7. Ahmad Ghosn A, Ralph Sinno R. Governing stresses in Z-purlin Lap Joints, *Journal of Structural Engineering, ASCE*, **121**(1995) 1735-41.
8. Chung KF, Ip KH. Finite element investigation on the structural behavior of cold formed steel bolted connections, *Engineering Structures*, **23**(2001) 1115-25.
9. Sally hosny Taha, Rimon Aziz Samaan et al. Behavior of overlapped cold Formed Z-Beams, *Journal of Engineering and Technical Research*, **2**(2014) 124-36.
10. Bayan A, Sariffuddin S, Hanim O. Cold formed steel joints and structures-A review, *Journal of Civil and Structural Engineering*, **2**(2011) 621-34.
11. Bryan ER. The design of bolted joints in cold formed steel sections, *Thin Walled Structures*, **16**(1993) 239-62.