INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH & DEVELOPMENT

ISSN: 2278 – 0211 (ONLINE)

Investigation On Cold – Formed Steel Lipped I-Beam With Trapezoidal Corrugation In Web By Varying Depth

G. Arunkumar
Assistant Professor, Department of Civil Engineering,
Government College of Engineering, Salem – 636 011,
Tamilnadu, India
P. Sampathkumar
P.G Student, Department of Civil Engineering, Government
College of Engineering, Salem, Tamilnadu, India
S. Sukumar
Professor, Department of Civil Engineering, Government
College of Engineering, Salem , Tamilnadu, India

Abstract:
The effect of web corrugation and h_w/t_w ratio on the flexural strength of cold formed steel (CFS) lipped I section is presented in this paper. Totally five specimens were experimented one with flat web and the remaining with trapezoidal corrugation in web. The length of the specimen is kept constant for 3600 mm and h_w/t_w ratio is varied from 333.33 to 583.33 keeping all other parameters constant. All specimens are experimented under two point loading with simply supported condition. The experimental results are verified with finite element analysis using ANSYS software. Experimental and numerical results are compared with the predicted resistance by North American Specifications (AISI S100-2007) and Australian/Newzealand Standards (AS/NZS: 4600-2005). The experimental result shows that the flexural capacity of the corrugated web is larger than flat web. Within the parametric study the effect of h_w/t_w ratio on the flexural strength capacity is discussed and presented.

Key words: *ANSYS, corrugation, cold-form steel, flexural strength.*

1. Introduction

In steel construction, there are two main types of structural members one is hot rolled section and the other is cold-formed section. Although cold-formed steel sections are used in car bodies, railway coaches, varies types of equipment, storage racks, grain bins, transmission towers, transmission poles etc but in building construction it has limited advancement. The use of hot rolled steel sections becomes uneconomical for the steel structures subjected to light and moderate loads. The structural members like purlin, girts, roof trusses, complete framing of one and two storey residential, commercial and industrial structures subjected to moderate load, for which cold formed steel members may be sufficient. Cold formed sections like Channel, Zee sections are commonly used flexure members for purlins & girts in roof and wall system [12]

In construction application, for economical design of flexural member thin web may be sufficient to transmit the shear in the beam while the flanges support major external loads, thus by using greater part of the material for the flanges. Material saving could be achieved without weakening the load-carrying capacity of the beam [7,13]. The flat web losses it stability when the compressive stress in the web exceeds the critical point before the occurrence of yielding. This could be improved by using corrugated web, an alternate to plane web, which produces higher stability and strength without additional stiffening and use of large thickness

Corrugated steel webs were recently proposed to replace the stiffened steel plates /box girders to improve the strength and the economy of the structure [6,10]. Researchers [1,2,5] have attempted to use corrugated plate in the webs of hot-rolled I-girder. This can overcome the disadvantages of conventional stiffened flat webs. Such as web instability due to bending stress and fatigue failure.

Past researchers [8,9,11] investigated on I-girders with trapezoidal corrugation of hot rolled section. The research on cold-formed steel (CFS) of I-beam is limited. For flexure member subjected to light and moderate load, I section of thin flange and web may be sufficient. Thin flange may be stiffened by providing lip. Thin web may be stiffened by using corrugation. In recent times no studies have been reported on lipped I-beam with trapezoidal corrugation. This paper describes the details of such a study.

The aim of this paper is to study the effect of web corrugation and h_w/t_w ratio in flexural strength of cold- formed steel (CFS) lipped I section with trapezoidal corrugation in web under two point loading.

In this study, five specimens are experimented one with flat web and the remaining with trapezoidal corrugation in web by varying the h_w/t_w from 333.33 to 583.33 are investigated. For all the sections theoretical analysis is performed using codal provision such as North American Specifications (AISI S100-2007) and Australian/New Zealand standards (AS/NZS:4600-2005). The experimental investigation has been carried out on all specimens with the help of 500 kN loading frame. The numerical model is developed using finite element software ANSYS 12.0 including both material and geometric non linearity to simulate the experimental results. The effects of h_w/t_w ratio are discussed.

2. Experimental Investigation

The specimens are fabricated by locally available cold formed sheets. The CFS sheet of 2mm is used for flanges and 1.2mm for web. Flanges and web are connected by continuous thin weld. The profile, cross section and corrugation profile are in Fig.1,2, and 3 respectively. At the loading point and support a stiffener of 3mm plates are placed in order to avoid the bearing failure and distribute the load uniformly. Totally five specimens were fabricated Fig.4 shows the entire fabricated specimen. The details of the specimens fabricated and their dimension details with labeling are given in Table.1

Model No.	a mm	b mm	c mm	d_{max} mm	ϴ	t_w mm	h_w mm	b_f mm	t_f mm	b_l mm	t_l mm	L mm	h_w/t_w
TCWD1	60	42.42	60	21.21	45^o	1.2	400	150	2	15	2	3600	333.33
TCWD2	60	42.42	60	21.21	45^o	1.2	500	150	2	15	2	3600	416.67
TCWD3	60	42.42	60	21.21	45^o	1.2	600	150	2	15	2	3600	500.00
TCWD4	60	42.42	60	21.21	45^o	1.2	700	150	2	15	2	3600	583.33
TCWD5	-	-	-	-	0^o	1.2	400	150	2	15	2	3600	333.33

Table 1: Dimensions of Specimens

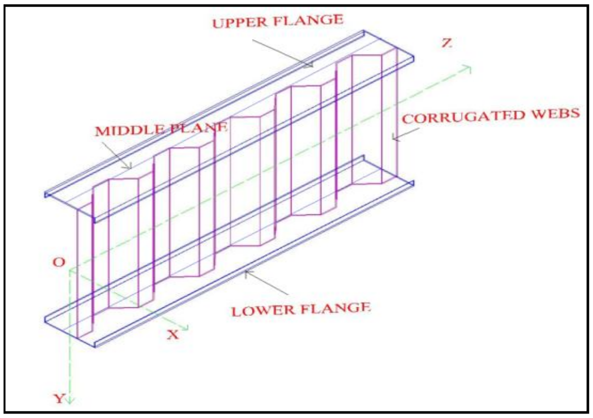

Figure 1: Profile of Lipped I-beam with corrugated web

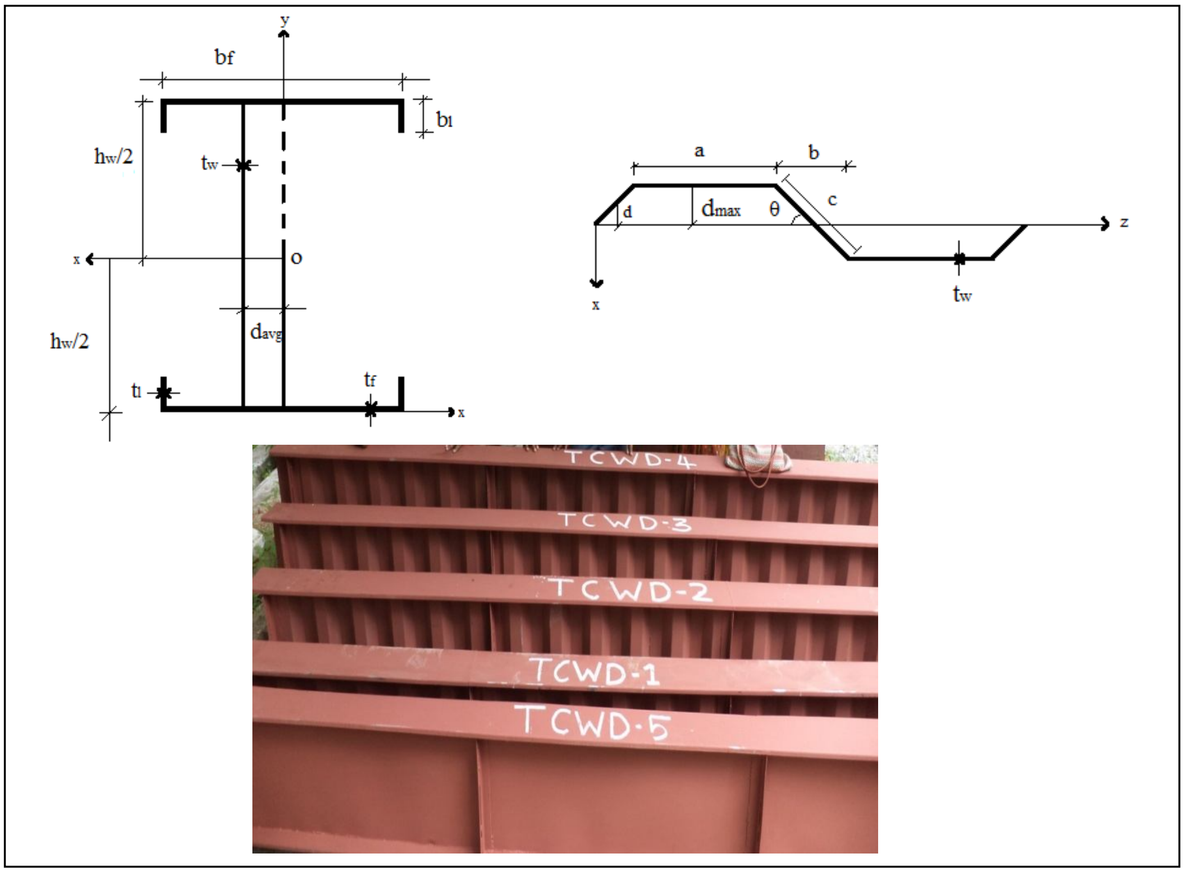

Figure 4: Fabricated Specimens

The material properties of CFS specimens are determined by tensile coupon tests confirming to the Indian standard IS 1608-2005 (Part-1). Stress Vs strain graph of coupon test is shown in Fig.5.Tested coupon specimen is shown in Fig.6.The properties obtained from coupon test are listed below

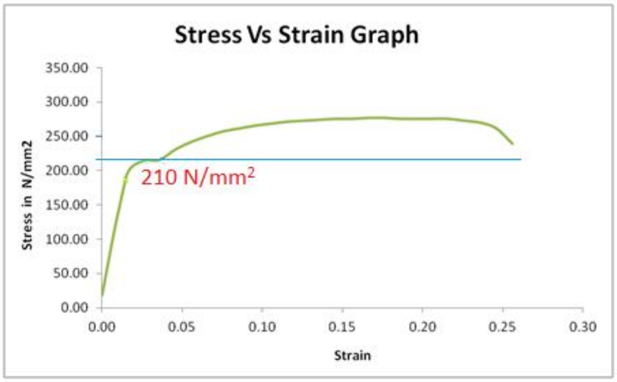

Figure 5: Stress Vs Strain graph for coupon test

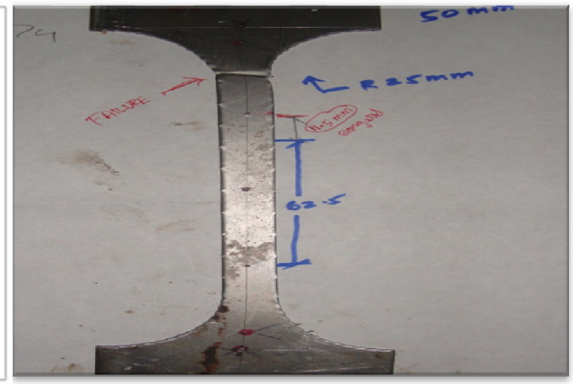

Figure 6: Specimen after test

Yield Stress (f_y) = 210 Mpa

Young's Modulus (E) = 200 GPa

Poisson's Ratio (m) = 0.3

3. Test Setup

Specimens are tested in a loading frame of capacity 500 kN under two point loading at l/3 distances shown in Fig.7. The schematic diagram of the test setup is shown in Fig.8. A hinged support is provided at the ends, In order to avoid the lateral displacement and tilting of specimen a lateral clamping is given at ends of the specimen. LVDT's and load cell are used for measuring deflection and load increment. All the data are recorded in a Data acquisition system.

Figure 7: Experimental setup

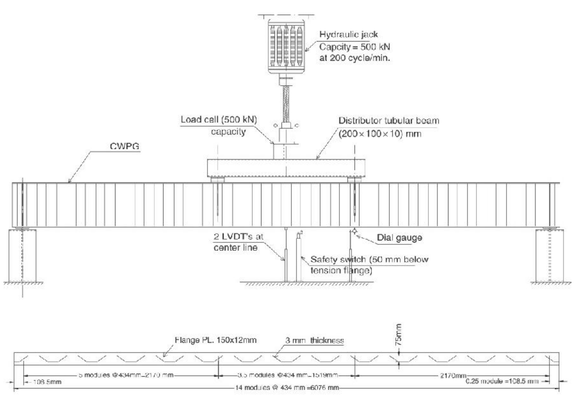

Figure 8: Schematic diagram of experimental setup

Specimen Name	Depth (mm)	Angle	Flexural capacity (kNm)	Failure Mode of specimen
TCWD1	400	45^o	29.91	Local buckling of top compression flange + Lateral torsional buckling
TCWD 2	500	45^o	33.84	Local buckling of top compression flange + Lateral torsional buckling
TCWD 3	600	45^o	39.05	Local buckling of top compression flange + Lateral torsional buckling
TCWD 4	700	45^o	42.56	Local buckling of top compression flange + Lateral torsional buckling
TCWD 5	400	0^o	24.61	Local buckling in the web + crushing on top flange

Table 2: Experimental Results

The experimental flexural capacity and failure mode of each specimen is summarized in Table.2. TCWD5 specimen fails by initiation of local buckling in web of shear zone and then leads to crushing on top compression flange. All other specimens fail due to initiation of local buckling of top compression flange and followed by lateral torsional buckling.

From the experimental results it is found that as the depth increases the flexural capacity also increases within the parametric study.

It is noted that the percentage increase in flexural capacity of the corrugated specimen when compared to flat web specimen is about 15%.

4. Numerical Analysis

All the tested specimens of lipped I-beam with trapezoidal corrugation in web are investigated numerically using the finite element software ANSYS.12. All the specimens are modeled with four node shell 181 elements. The residual stresses of the sections are not included in the model. The strain hardening of the corners due to cold forming is neglected.

An appropriate mesh size is chosen after mesh sensitivity analysis. The young's modulus of E=20000 N/mm^2 and the yield stress of fy=210 N/mm^2 are considered for the materials. In order to account the elasto-plastic behavior, a bilinear stress-strain curve is adopted, having tangent modulus Et = 0.1E = 20000 N/mm^2.

In the modeling support condition is given by restraining u_x, u_y, u_z at one end and restraining u_x and u_y at other end. In the support at the centre node of the web u_x, θ_x are restrained for lateral clamping. The web and flanges are connected by coupling at each node throughout the section, shown in Fig.9. An Eigen buckling analysis is performed to obtain first buckling mode shape. The scaled first elastic buckling mode shape is used to create a geometric imperfection. This is followed by a non-linear analysis. The material and geometric non-linearity is included in the finite element model. The non-linear finite element analysis performed for all the specimens and flexural moment capacity obtained is shown in table.

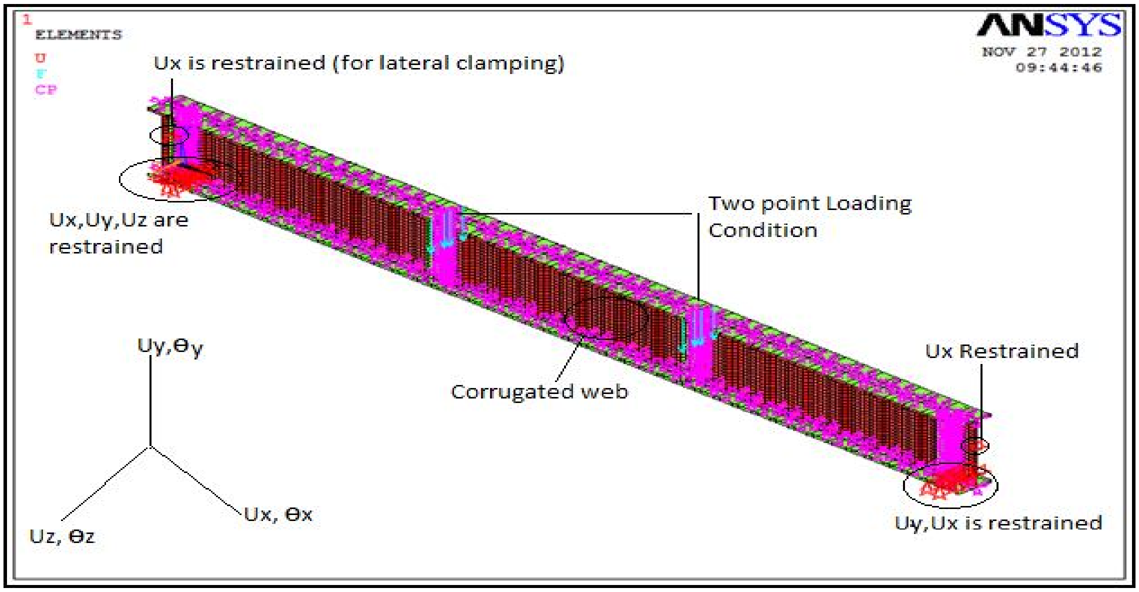

Figure 9: Loading and boundary condition of analysis model

5. Validation of the results

Experimental results of all the five specimens are used to verify the efficiency of the numerical model in predicting flexure and the corresponding response of the tested specimens.

Experimental flexural capacity M_{test} and Finite element analysis flexural capacity M_{FEA} result are compared in Table.3 which shows good agreement. The mean and standard deviation of the experimental to FEA flexural capacity ratio are 1.0159 and 0.0318 respectively. As an example, the load versus deflection curve obtained in finite element analysis is compared with the experimental curve of TCWD4 specimen (Fig.14) and it closely matches with the experimental result.


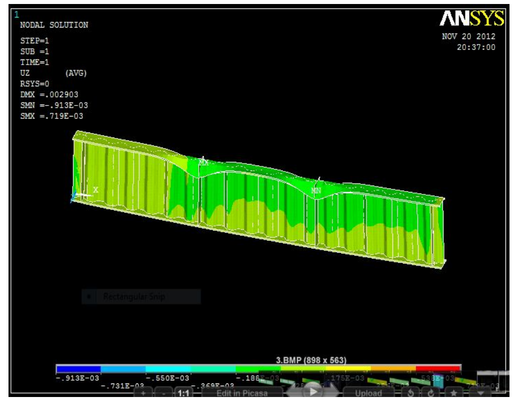

Figure10: Experimental Failure mode of TCWD4, Figure11:FEA Deformation mode of TCWD4

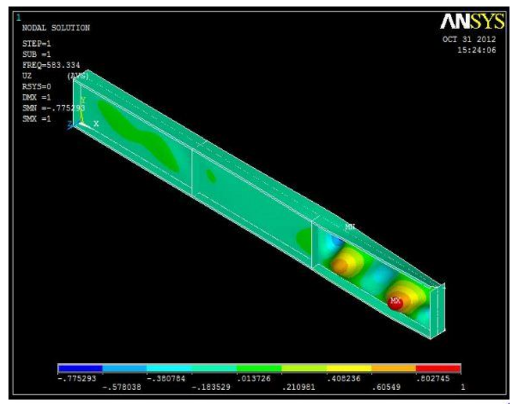

Figure12: Experimental Failure mode of TCWD5, Figure 13:FEA Deformation mode of TCWD5

Fig.10 and Fig.12 shows deformed shape of experimented specimens of TCWD4 & TCWD5. The specimen TCWD4 fails by initiation of local buckling in compression flange and then leads to lateral torsional buckling. The specimen TCWD5 fails in local buckling in shear zone of the web and then leads to local buckling in compression flange. Fig.11 and Fig.13 shows the deformed shape predicted by finite element analysis for the specimen TCWD4 and TCWD5 respectively. The deformed shape obtained from the FEA closely similar to the experimental buckling mode. Similar results were obtained for all other specimens.

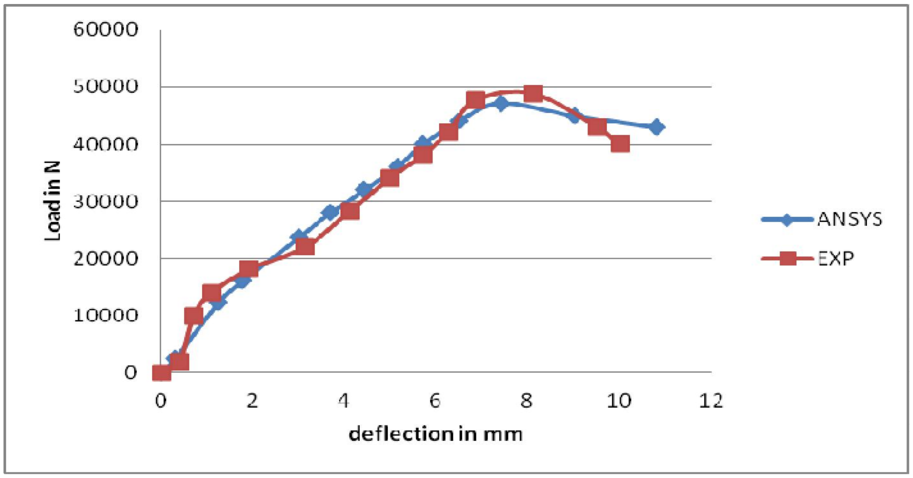

Figure 14: Comparison of Experimental and FE Analysis Load Vs Deflection

Specimen ID	Experimental flexural capacity(M_{test})(kNm)	FEA flexural capacity capacity(M_{FEA})(kNm)	M_{Test}/M_{FEA}
TCWD 1	29.91	28.73	1.041072
TCWD 2	33.84	33.01	1.025144
TCWD 3	39.05	38.26	1.020648
TCWD 4	42.56	41.23	1.032258
TCWD 5	24.62	25.63	0.960593
Mean			1.015943
Standard Deviation			0.031891

Table3: Comparison of Results

6. Theoretical Analysis

The theoretical results involves the analysis of cold formed steel lipped I-beam with corrugation in web for its moment carrying capacity obtained from Australian/ New Zealand Standards (AS/NZS 4600:2005) and North American Specifications (AISI S100-2007).The predominant mode of failure in all the specimen are lateral torsional buckling. The theoretical results compared to AS/NZS 4600:2005 and AISI S100-2007 are shown on the Table 4.

Specimen ID	Experimental Fl exural capacity (M_{test})(kNm)	Flexural capacity as per AISI (M_{AISI})(kNm)	Flexural capacity as per AS/NZS ($M_{AS/NZS}$)(kNm)	M_{test}/M_{AISI}	$M_{test}/M_{AS/NZS}$

TCWD 1	29.91	26.93	26.07	1.110657	1.147296
TCWD 2	33.84	31.85	30.76	1.06248	1.10013
TCWD 3	39.05	36.44	35.12	1.071625	1.111902
TCWD 4	42.56	40.75	39.20	1.044417	1.085714
TCWD 5	24.62	26.93	26.07	0.914222	0.944381
Mean				1.04068	1.077885
Standard Deviation				0.074725	0.07803

Table 4: Theoretical result Vs Experimental Results:

7. Discussion

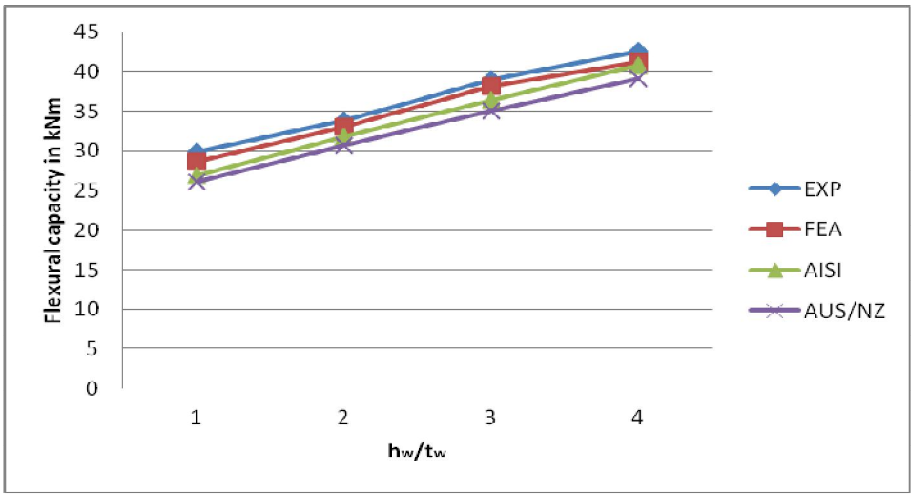

Figure 15: Comparison ultimate moment of Experimental and Numerical with h_w/t_w ratio

The plots for flexural capacity versus h_w/t_w (Fig.15) demonstrate the influence of changing the height of web on the flexural capacity. Within the parametric study it is observed that as the h_w/t_w ratio increases the flexural capacity also increases. According to AISI and As/Nzs h_w/t_w ratio is limited to 250 for design purpose. The mode of failure is initiation of local buckling in compression flange leading to lateral torsional buckling. From the experimental and numerical investigation it is noticed that bearing failure at the loading and support point is avoided by provision of 3mm thick plate. From the Fig.12 it is noticed that flat web fails by local buckling of web in shear zone. The percentage increase in flexural capacity of the corrugated specimen when compared to flat web specimen is about 15%. Though h_w/t_w ratio exceeded the limiting value 250 all the specimens. The flexural capacity is increased by providing corrugated web. From the Fig.15 it is observed that the moment carrying capacity obtained from Australian/ New Zealand standards (As./Nzs 4600:2005) and North American specification(AISI S100-2007) codes are conservative while compared with experimental and finite element analysis results.

8. Summary & Conclusion

This paper has described a detailed investigation on the structural behavior of cold formed steel lipped I-beam with trapezoidal corrugation in web. Both experimental and finite element analysis were conducted for better understanding of the behavior of the flexural member.

Finite element models of tested cold formed steel lipped I- beam with trapezoidal corrugation in web were developed using the advanced finite element by ANSYS. They were validated by comparing their result with the corresponding experimental results.

The test result are compared with the corresponding Australian/ New Zealand standards (As/Nzs 4600:2005) and North American specification(AISI S100-2007).

Based on the study, the following conclusions are drawn within the limit of the present investigation.

- The trapezoidal corrugation in web increases the flexural capacity of the beam.
- Numerical validation has been carried out to verify the appropriateness of the experimental results and find that they are quite closer to the corresponding test result.
- Failure due to shear in web is eliminated due to corrugation in the web.
- The results obtained based on the various codes are conservative.

9. Reference

1. Abbas, H.H., Sause, R., Driver, R. G., (2006), "Behavior of corrugated web I-girders under in-plane loading", Journal of structural Engineering, ASCE, Vol.132(8), pp:806-814
2. Abbas, H.H., Sause, R., Driver, R. G., (2007), "Analysis of flange transverse bending of corrugated web I-girders under in-plane loads. Journal of structural Engineering, ASCE, Vol.133(3), pp:347-355
3. AISI S 100:2007, "North American specification for the design of cold formed steel structural members specifications.
4. AS/NZS 4600:2005, "Australian/New Zealand Standard – Cold formed Steel Structures
5. Driver, R.G., Abbas, H.H., Sause, R., (2006), "Shear behavior of corrugated web bridge-girders", Journal of structural Engineering, ASCE, Vol.132(2), pp:195-203
6. Elgaaly,M., Hamilton, R.W., and Seshadi,A., (1996), "Shear strength of Beams with corrugated webs", Journal of Structural Engineering, ASCE, Vol.:122(4), pp:390-398.
7. Jiho moon, Jong-won yi, ByungM.choi, Hak-Eunlee,(2009), "Lateral torsion-flexure buckling of I-girder with corrugated webs under uniform bending", Thin-walled structures, Vol:47, pp:21-30
8. Khalid,Y.A., Chan,C.L., Saheri,B.B., Hamouda, A. M.S., (2004), "Bending behavior of corrugated web beams", Journal of materials processing Technology, Vol.150, pp:242-254
9. Linder, J., (1990), "Lateral torsional buckling of beams withtrapezoidally corrugated webs", Stab Steel structures Budapest, Hungary, pp:305-310
10. Sayed-Ahmed, E.Y., (2005), "Lateral torsional-Flexure buckling of corrugated web st eel girders", Proceeding Inst Civil EnggStruct Building, Vol.58, pp53-69
11. Sayed-Ahmed, E.Y. (2001), "Behaviour of steel and /or composite with corrugated steel webs", Canadian Journal of Civil Engineering, Vol.28, No.4, pp.656-672.
12. Yu,W. W.,(1991), Cold-formed steel design, John wiley& sons, New York, pp-522-540.
13. Zhang,W., Li, Y., Zhou, Q., Qi, X., Windera, G. E. O., (2004), 'Optimization of the structure of an H-beam with either a flat or a corrugated web, part 3. Development and research on H-beams with wholly corrugated webs", Journal of materials processing Technology, Vol: 101, pp: 119-123.