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Investigation on the Flexural Behaviour of Steel Cold Formed Built Up Sections

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Abstract: For the past few decades, substantial progress has been made in material properties and construction methodology, which demands in need of development of stronger and lighter members in structural steel applications. The demands of increase in strength and reduction in weight of sections leads to development of structures which are slender and also stability plays a major role in design. The main goal of this study is to develop and investigate the performance of build-up steel I beam sections with corrugated webs. This study focuses on analysis of flexural behaviour and failure modes of plain web, rectangular, trapezoidal web and triangular web in beams by experimental investigations using three-point load test and analytical investigations using ANSYS software. From experimental and analytical analysis, triangular corrugated web beam performs better compared to all section. The experimental results obtained are more similar to analytical results obtained by ANSYS software with only slight deviations. The failure modes in both experimental investigation and analytical analysis are similar.

Keywords: Cold formed steel, corrugated web, flexural test, ANSYS

1. Introduction

Cold formed sections (CFS) are most commonly adopted in light weight structures, storage racks and grain bins. The cold formed section can be combined with corrugated plate of varying profile and thickness so that the advantages of corrugation can be effectively implemented in cold formed light gauge beam to enhance the properties of section [1]. The corrugated steel plate has various favourable properties hence it is used in many structural applications. The most commonly used structural members in steel constructions were cold formed sections and hot rolled sections [2,3]. Now a days, cold formed sections are used in various applications compared to hot rolled members since the weight of hot rolled members are much heavier on comparing with cold formed members [4]. The fabrication of these cold formed members in required shapes can be done at normal temperature by rolling and pressing the flat sheets that can support more loads compared to flat sheet. The nominal thickness of cold formed steel section are usually 3mm [5]. The yield stress of steel used is 250 MPa [6]. Since the steel manufactures fabricate high strength steel in large quantity as efficiently, the higher yield stress steels are most commonly used. The structural engineers encounter more difficulty in structural problem because of usage of thinner sections and high strength steels which are not normally occurs in general structural design [7]. Due to this change in steel sections, the structural instability of the steel sections occurs as result of this reduced buckling capacity of the section and yield stress and buckling stress of this sections are almost

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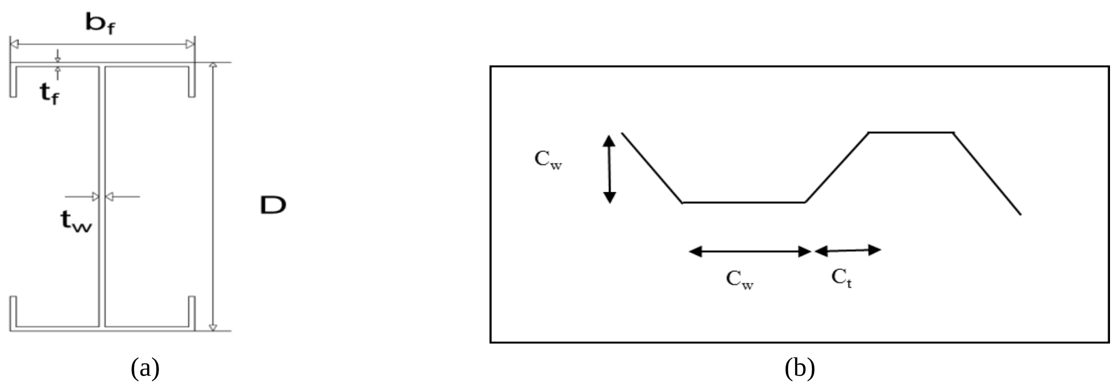
equal because of use of high strength steel [8]. The cold formed steel section are mostly used in industries nowadays and has wide range of application. For the past fifty years, several researches have been done to study behaviour of cold formed steel beam sections [9], [10]. Even though several researches have been undergone in this field for the past decades, the finality of this research is still unreached. In the beginning of this century, due to increase in demand of using strong and light sections in wide range of applications, there is a substantial progress in this field. This demand of use of these sections are made possible by developing theory and understanding its behaviour under load, economic consideration, construction techniques, construction efficiency etc. These advancements in developments changes the traditional way of design and make this steel sections as economical [11]. Due to the need of high strength and light weight sections, the sections are to be made slender considering the stability during the design [12]. The stability of sections is based on the strength and slenderness of that sections. In I sections, the shear stresses which are developed due to external loads are taken up by thin webs. If the web in I section shows instability, then the stiffeners can also be provided to compensate the stability problems. To eliminate the use of stiffeners, corrugations in the web portion can be provided [13]. This corrugated wen provides more lateral stiffness compared to flat webs. Generally, in corrugated web beams, two flanges are connected to the corrugated web by means of welding [14]. The corrugated web beams are advantage to the construction industry, due to maximum lateral stiffness of beam. The main aim of the present investigation is to analyse behaviour of beam with corrugated web and plane web, by experimental approach and by theoretical approach by using ANSYS and to compare both experimental and theoretical results [15].

2. Fabrication of Test Specimens

The specimens were fabricated from locally available cold formed sheets (CFS). CFS sheets of 1.5mm thick were used for flanges and 1.5mm for web. The flanges with lip of 15mm on both sides and corrugation of web were made by cutting the sheets to desired length and formed by pressing and bending [16]. Flanges and web were connected by spot welding at the nodal points. The geometric properties of various types of corrugation profiles of cold formed steel beam are as shown in Table 1 and section parameters of different sections are shown in Fig. 1.

Table 1 - Geometric parameters

Parameter	Plain web	Trapezoidally corrugated web	Rectangular corrugated web	Triangular corrugated web
Overall depth (D)	300mm	300mm	300mm	300mm
Width of flange (b_f)	150mm	150mm	150mm	150mm
Thickness of flange (t_f)	1.5mm	1.5mm	1.5mm	1.5mm
Thickness of web (t_w)	1.5mm	1.5mm	1.5mm	1.5mm
Depth of web (d)	297mm	297mm	297mm	297mm
Length of lip	15mm	15mm	15mm	15mm
Length of Beam	800mm	800mm	800mm	800mm
Corrugation width (C_w)	-	50mm	100mm	50mm
Corrugation depth (C_t)	-	35mm	20mm	25mm
ϴ	-	45	90	45
Slenderness Ratio	22.8	23.02	23.54	23.21



(a) (b)

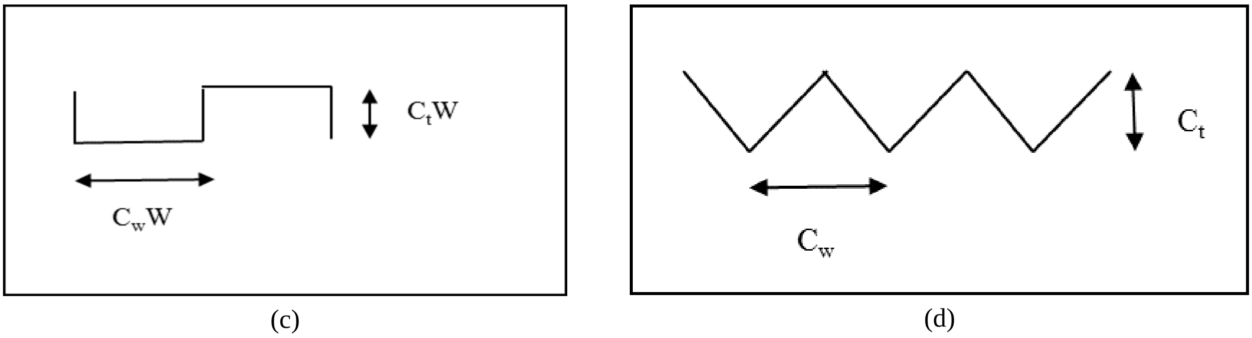


Fig. 1 - Section Parameters (a) Plain Web; (b) Trapezoidal Corrugated Web; (c) Rectangular Corrugated Web; (d) Triangular Corrugated Web

3. Test Setup

The experimental investigation was carried out in a 500 kN capacity loading frame. The schematic diagram is shown in Fig. 2 and Schematic representation of trapezoidal corrugated web lipped I beam is shown in Fig. 3. A load cell was used to monitor the applied load. Central point loads were applied on each beam using hydraulic jack with a loading span of 700 mm. To avoid the lateral displacement and tilting of the specimen, lateral clamping of web was made at the supports of the specimen. The deflectometer was fixed at the midpoint of beam to measure the displacements in beam. The load specimens were loaded until the specimen became unstable and load started decreasing. The load at which the specimen fails is observed and noted as the critical load [17].

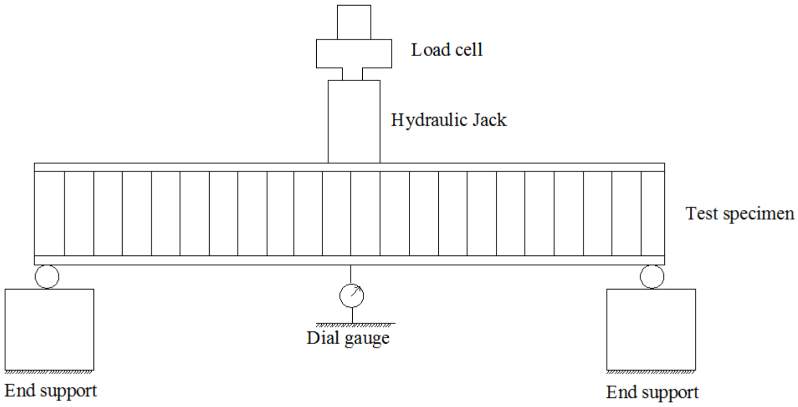


Fig. 2 - Experimental setup of beam specimen

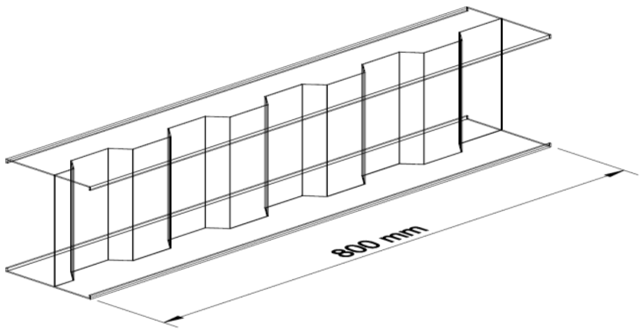


Fig. 3 - Diagrammatic representation of trapezoidal corrugated web lipped I beam

4. Experimental Investigation

A comparative deflection curve for Plain, Trapezoidal corrugated, Rectangular corrugated and Triangular corrugated are plotted and studied [18]. The moment capacity due to experimental investigation are obtained. Plain web has moment capacity of 2.45 kNm. However, for trapezoidally corrugated web, rectangular corrugated web and triangular corrugated web has moment capacity of 4.9 kNm, 4.2 kNm, 6.3 kNm respectively. The failure mode of plain web is due to lateral buckling, whereas for trapezoidally corrugated web, rectangular corrugated web and triangular corrugated web, the failure mode is due to lateral torsional buckling. On comparing the test results obtained experimentally, it is found that triangular corrugated web has maximum moment capacity compared to all specimens, which is 88% higher than moment capacity of plain web. Table 2 shows the flexural capacity of differed types of cold formed steel beams. Fig. 4 to Fig. 6 shows their corresponding failure modes, while the load vs displacement results are shown in Fig. 10 to Fig. 13.

Table 2 - Experimental test results for flexural capacity

Test No.	Specimen ID	M experimental (kNm)	Failure Mode
1	Plain web	2.45	Lateral buckling
2	Trapezoidally corrugated web	4.9	Lateral Torsional Buckling
3	Rectangular corrugated web	4.2	Lateral Torsional Buckling
4	Triangular corrugated web	6.3	Lateral Torsional Buckling

Fig. 4 - Failure pattern of trapezoidal corrugated web

Fig. 5 - Failure pattern of plain web

Fig. 6 - Failure pattern of rectangular corrugated web

5. Analytical Investigation

In analytical investigation, to compare analytical results with experimental results, finite element models were simulated [19] and were confirmed by using load-deflection curves, deflected shapes and moment capacities. Load deflection curves for various specimens were drawn. The loads are applied in increments of 2 kN using load step method. Plain web has moment capacity of 2.4kNm. However, for trapezoidally corrugated web, rectangular corrugated web and triangular corrugated web has moment capacity of 4.7 kNm, 4.1 kNm, 6.0 kNm respectively. On comparing the test results obtained experimentally, it is found that triangular corrugated web has maximum moment capacity compared to all specimens, which is 85.7% higher than moment capacity of plain web. The triangular web configuration has more strength when compared with rectangular, trapezoidal and plain web configuration. From the result, it was concluded that developed models are sufficiently accurate to simulate buckling behaviour of cold formed corrugated steel I-beam. The analytical curves for the load deflection curves presented in Fig. 10 to Fig. 13. The failure pattern is shown in Fig. 7 to Fig. 9. The failure occurs in plain web cold formed beam by lateral buckling. The stress concentration occurs near the central point. The failure of corrugated beam is accomplished by lateral torsional buckling and local buckling of flange plate. The flexural capacity of plain and corrugated web I beam is tabulated in Table 3.

Table 3 - Analytical results for flexural capacity

Test No.	Specimen ID	M analytical (kNm)	Failure Mode
1	Plain web	2.40	Lateral buckling
2	Trapezoidally corrugated web	4.7	Lateral Torsional Buckling
3	Rectangular corrugated web	4.1	Lateral Torsional Buckling
4	Triangular corrugated web	6.0	Lateral Torsional Buckling

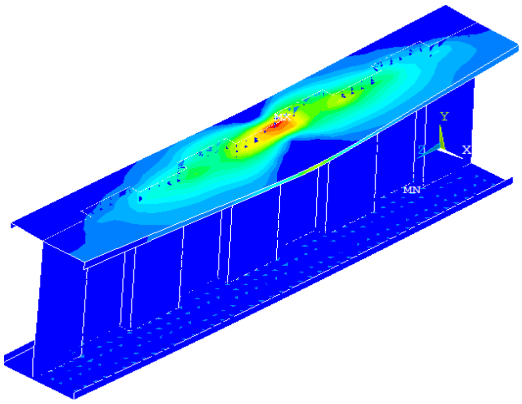


Fig. 7 - Failure pattern of plain web

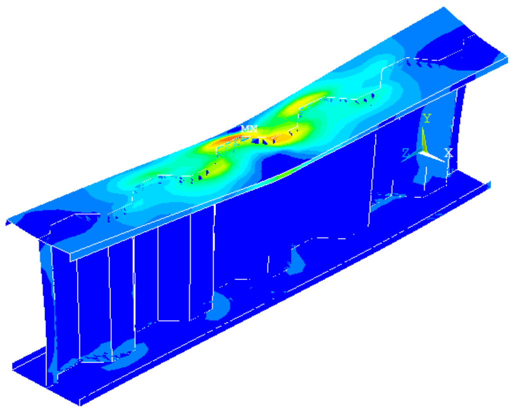


Fig. 8 - Failure pattern of trapezoidal corrugated web

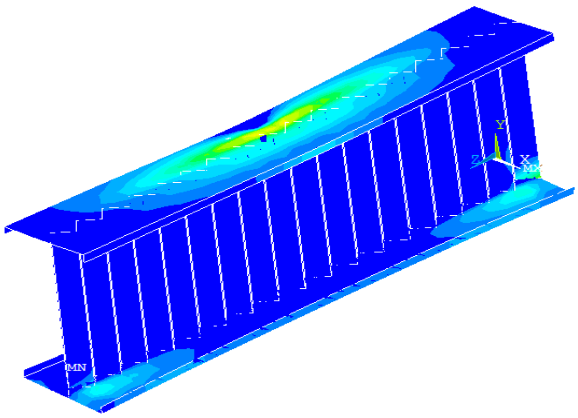


Fig. 9 - Failure pattern of triangular corrugated web

6. Comparison of Experimental and Analytical Results

The load deflection curve for experimental investigation are compared with analytical results and are displayed in Fig. 10 to Fig. 13. The deflection curve shows that there exists a linear relationship till maximum load is reached and there is sudden sharp decrease in curve indicating that the specimen has reached its limit. The load at this point is the critical load of the specimen. By comparing the failure modes of experimental investigation and analytical investigation, the developed model accuracy can be found out [20], [21]. Both finite element model and experimental have been in agreement over critical load and linear variation of load deflection curve. These results are in similar trend with the results of Divahar et al. [22] where he attains the deviation of 2 to 8%.

On analysing the experimental results, it can be concluded that triangular corrugated web performs better than other corrugated and plain beams. It can withstand maximum moment capacity due to the less corrugation depth and 45^0 angle of inclination of corrugated flange sections. On finite element analysis, the results obtained are almost similar to the results of experimental investigation, showing that triangular corrugated web performs better compared to all sections. From both experimental and analytical investigations, the results found that triangular has more stiffness among all configurations and rectangular has the least stiffness of all. This least stiffness of rectangular corrugated web is due to its 90^o angle of inclination of corrugations. The results are in similar trend with results of Dmitry Shlyakhin et al. [23] where he studied and concluded that triangular corrugated web performs better than sinusoidal corrugated web. In both experimental and analytical studies, plain web fails due to lateral buckling due to thinner section of web and other sections fails due to lateral torsional buckling due to the gap in web section.

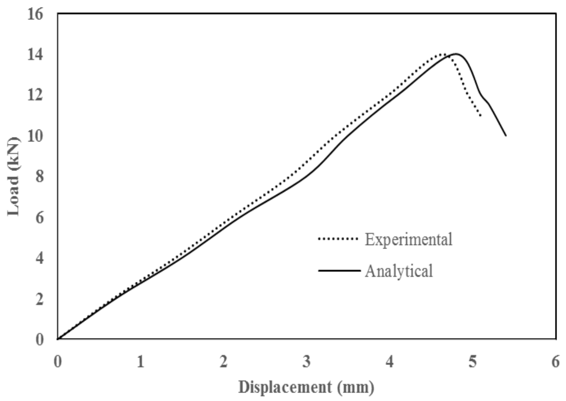


Fig. 10 - Load vs deflection for plain web

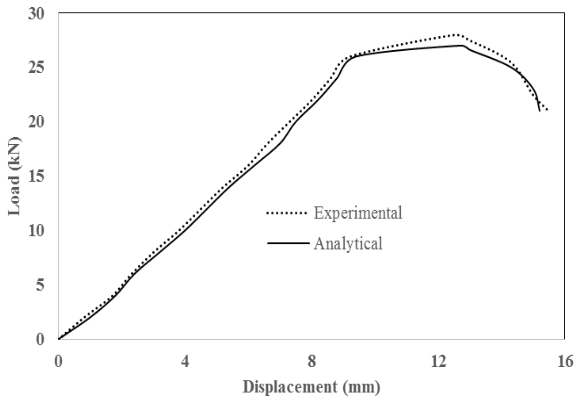


Fig. 11 - Load vs deflection for trapezoidal corrugated web

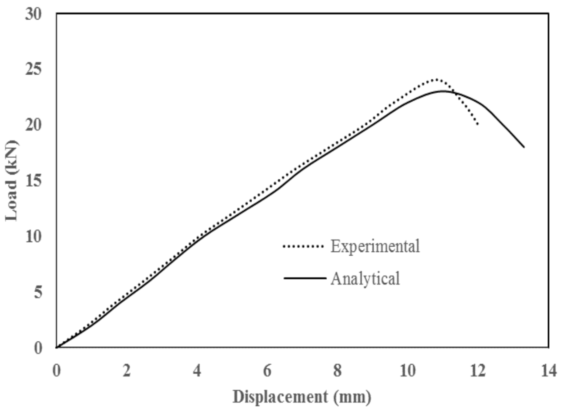


Fig. 12 - Load vs deflection for rectangular corrugated web

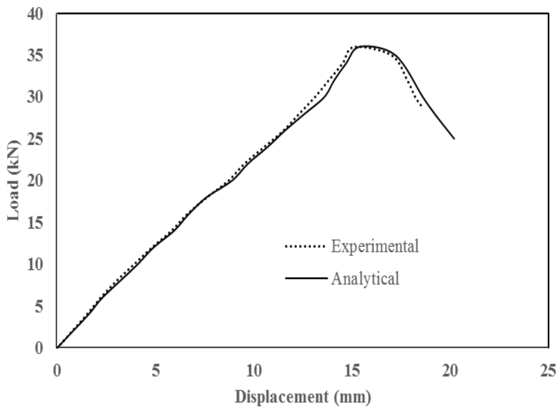


Fig. 13 - Load vs deflection for triangular corrugated web

8. Conclusion

The following conclusions are made from the experimental and analytical investigations,

- For the constant depth and thickness the triangular corrugated web profile has nearly 157% greater flexural strength when compared with rectangular and trapezoidal configuration.
- The trapezoidal corrugated web has 70% more flexural strength when compared with rectangular corrugated web.
- The flexural strength in rectangular corrugated web is two times higher than plain web.
- The deflection in triangular corrugated web is reduced to nearly one third when compared with plain web configuration.
- The rectangular corrugated is more susceptible to buckling when compared with other corrugated web and has higher deflection of the three corrugated specimens.

- Failure occurs in all three corrugated specimens by lateral torsional buckling while lateral buckling takes place in Plain web configuration.

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