Experimental Investigation on the Flexural Behaviour of Cold Formed Corrugated Steel Channel Sections

Sureshbabu S, SenthilSelvan S

Abstract*— This paper describes the experimental investigation on flexural behavior of cold formed steel (CFS) lipped channel corrugated section .Cold-formed steel is getting popular over the years in construction industry. However, due to its thin-walled behaviour, cold-formed steel is prompt to have buckling failure, previous research were done to provide stiffener in order to overcome this problem. In this research paper three different sets of corrugated sections have been taken for testing flexural behaviour namely (i)horizontal corrugated back to back lipped channel sections without gap (ii) horizontal corrugated back to back lipped channel sections with gap and (iii) vertical corrugated lipped channel sections by providing corrugation angle in horizontal and vertical direction. Corrugated section of cold-formed steel behave differently in beam and column compared to straight section. Corrugated section has an advantage of exhibit distinct enhancement in ultimate strength and reduced deflection in flexural behaviour. Both the Experimental and Analytical study were carried out for the chosen specimens respectively. It was noticed from the Analytical results that there was an increase in Ultimate Load carrying capacity for the vertically corrugated section. For the selected corrugated sections, it was observed from the Experimental values that the ultimate load carrying capacity was increased by 9.7% in the vertically corrugated section. This would have been because of the provision of stiffeners at the edge and web of the section.

Keywords: cold-formed steel, corrugation angle, flexural behavior

1. INTRODUCTION

Cold-formed steel sections are developing at a rapid rate such that they are used as a common method of constructing light-weight floors and portal frame structures. In fact it can be said that cold-formed steel (CFS) construction is now one of the highly competitive alternative to traditional structural system. Some of the widely acknowledged advantages of CFS framings are: lighter weight, reduces transport and handling costs, ease of prefabrication and mass production. The optimal design of CFS system is important in ensuring that they can produce a cost-effective solution which is somewhat lagging in other types of structural systems.

In the previous research work many researchers 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 investigated on I-girders with trapezoidal corrugation for hot rolled section. The use of corrugated webs is a potential method to achieve adequate out-of-plane stiffness and shear buckling resistance without using stiffeners; therefore, it considerably reduces the cost of beam fabrication and the weights of superstructures. Because the corrugated web carries only shear forces and the flanges carry the moment due to effect. In order to benefit from these characteristics, prestressed concrete box girder bridges with corrugated webs are used extensively. Shear stresses can cause the failure of the web by shear buckling or yielding depending on the geometric characteristics of the corrugated webs. The literature studies on corrugated webs are mostly restricted for shear buckling only. Recently, several researchers have attempted to use corrugated plates in the webs. This can overcome the disadvantages of conventional stiffened flat web failure such as web instability due to bending stress and fatigue failure. This paper investigates the flexural behaviour for cold-formed steel beam corrugated section with a longitudinal span of 1200 mm.

2. EXPERIMENTAL PROGRAMME

2.1Material Properties:

The specimens used in the present investigation were fabricated from cold-formed steel sheets of different thicknesses. The yield strength, ultimate tensile strength and percentage elongation of the material were determined by tensile coupon tests confirming to ASTM A 370 [6].The yield stress was determined by the offset method since cold-formed steel is gradually yielding. The yield point of the steels recommended for cold-forming by the AISI ranges from 172 to 482 N/mm^2 and the attained value was 257N/mm^2. Similarly the ultimate tensile strength of the steel was obtained as 390N/mm^2 and the specifications in the AISI standards ranges from 289 to 584 N/mm^2 and the ratio of tensile strength to yield strength ranges from 1.21 to 1.8 while the obtained value was around 1.52. The minimum percentage elongation recommended by the AISI ranges from 12 to 27 which was attained as 14 for the chosen. Normally cold form steel has the following properties: Density of steel (δ_s) : 0.000000785 N/mm^3, Poisson's Ratio (μ):0.3, Young's modulus of steel (E_s): 203395.33 Mpa.

2.2 Specimen Details:

Each specimen was manufactured by Press braking method to the required shape from the steel sheets of required thickness and then they are processed and

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fabricated at the industry. All the three of the chosen specimen are nothing but an I-beam provided with vertical and horizontal corrugations. The I shaped open section is made by connecting two lipped channel section with web stiffener. This lipped channel section is connected back to back by cover plate using weld. The web stiffened element is inclined at 45^{o} angle which is the provided corrugation. Thickness of the specimen is 2.5mm and longitudinal span of the beam is 1200mm.

2.2.1 Back to Back horizontally corrugated beam without spacing (Beam-1)

The first specimen taken was the beam made of two horizontally corrugated channel sections fabricated back-to-back without spacing in between them. The sectional dimension of the specimen consists of an overall depth of 190mm with a flange width of 140mm and provided with a 25mm long lip at the ends of the flange. The beam is fabricated with a thickness of 2.5mm and for a span of 1200mm with a provision 45^{o} corrugation angle as shown in Figure 1.

Depth of the beam	=190mm
Width of the beam (flange) =	140mm
Lip of the section =	25mm
Length of the specimen =	1200mm
Thickness =	2.5mm
Corrugation Angle =	45^{o}

Fig.1 Sectional specifications of beam corrugated horizontally back-to-back without spacing

2.2.2 Back to Back horizontally corrugated with Spacing (Beam-2)

This specimen is similar to that of the previous beam made of two horizontally corrugated channel sections fabricated back-to-back but with a spacing of 25mm between them. Since the channels are separated with a gap of 25mm cover plates were provided at top and bottom of the plate throughout the span of the specimen.

The specimen comprises of an overall depth of 190mm with a flange width of 165mm and with 25mm long lips at the ends of the flanges. The specimen is also provided with a 2.5mm thick cover plates at top and bottom for a width of 165mm throughout the span of the specimen. The overall span of the beam is 1200mm with 2.5mm thickness of the section and a provision of 45^{o} horizontal corrugation as shown in Figure 2.

Depth of the beam =	190mm
Width of the beam (flange) =	165mm
Length of the specimen =	1200mm
Thickness =	2.5mm
Spacing =	25mm
Plate	
Length of the plate =	1200mm
Width (for beam-1) =	140mm
Width (for beam-2) =	165mm

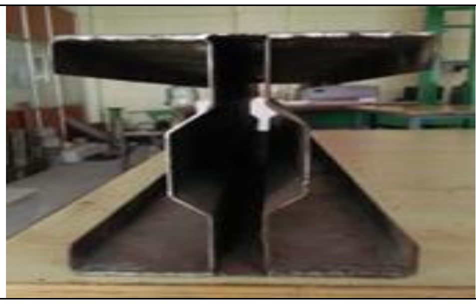

Fig.2 Sectional specifications of beam corrugated horizontally back-to-back with a spacing of 25mm

2.2.3 Beam with Vertical corrugation (Beam-3)

This specimen is provided entirely with vertical corrugation throughout the span of the specimen. The sectional dimension of the specimen consists of an overall depth of 190mm with a flange width of 140mm and provided with a 25mm long lip at the ends of the flange. The beam is corrugated for an angle of 45^{o}, with a thickness of 2.5mm and for a span of 1200mm as shown in Figure 3.

2.2.3 Beam with Vertical corrugation (Beam-3)

Depth of the beam =	190mm
Width of the beam(flange)=	140mm
Lip of the section =	25mm
Length of the specimen =	1200mm
Corrugation Angle =	45^{o}

Fig.3 Sectional specifications of beam provided with vertical corrugation

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2.3 Experimental Setup:

The testing was carried out in a loading frame of 100 Ton capacity. All the specimens were tested for flexural strength under two point loading. The specimens were arranged with simply supported conditions having an effective span of 1.2 m. Loads were applied at one-third distance from the supports through a hydraulic jack of 30 ton capacity at a uniform rate till the ultimate failure of the specimens occurred. Beam deflections were measured at several locations using Linear Variable Displacement Transducers (LVDTs) as shown in the Figure. Strain gauges and LVDTs were connected to a data logger from which the readings were captured by a computer at every load intervals until failure of the beam occurred. The experimental set-up for the test specimen is shown in Figure 4.

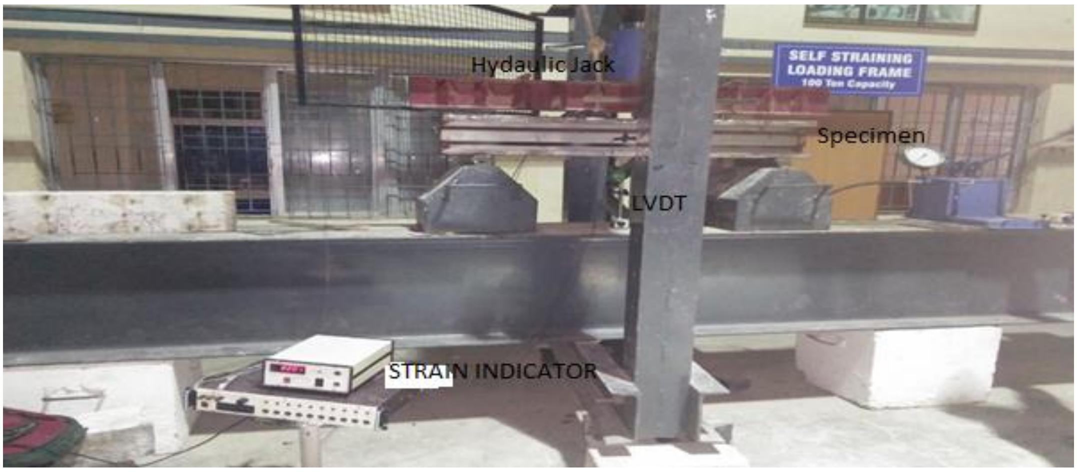

Fig 4 Experimental set-up for the test specimen

3. EXPERIMENTAL TEST RESULTS

3.1 Back to Back horizontally corrugated beam without Spacing (Beam-1)

The beam-1 specimen which was fabricated with horizontal corrugation without any intermediate spacing of 1.2m was set in a 100 Ton capacity loading frame. A spandrel beam with two loading points situated at one third of distance from the supports was placed over the specimen as shown in Figure 5 and the load was applied at a uniform rate from a 30 ton capacity hydraulic jack till the failure of the specimen was obtained. Linear Variable Differential Transducer (LVDT) was attached at the bottom mid-span of the specimen for measuring the displacement. An ultimate load of 30 KN was obtained corresponding to which a deflection of 6.35mm was recorded.

Fig 5 Deflection of Horizontally corrugated beam without spacing

3.2 Back to Back horizontally corrugated beam with Spacing (Beam-2)

The horizontally corrugated beam with a spacing of 25mm was placed on the 100 Ton capacity loading frame for a span of 1.2m. The two point loaded spandrel beam was placed over the specimen as shown in Figure 6 and the loading was applied at a uniform rate through a 30 Ton capacity hydraulic jack until the failure of specimen had occurred. Displacement was measured at the bottom mid-span of the specimen using LVDT. A deflection of 3.69mm was recorded for an ultimate

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load of 18KN for the tested specimen.

Fig 6 Deflection of Horizontally corrugated beam with a spacing of 25mm

3.3 Beam with Vertical corrugation (Beam-3)

The beam-3 specimen which was fabricated with vertical corrugation was set in a 100 Ton capacity loading frame. A spandrel beam with two loading points situated at one third of distance from the supports was placed over the specimen as shown in Figure 7 and the load was applied at a uniform rate from a 30 ton capacity hydraulic jack till the failure of the specimen was obtained. Linear Variable Differential Transducer (LVDT) was attached at the bottom mid-span of the specimen for measuring the displacement. An ultimate load of 31KN was obtained corresponding to which a deflection of 5.53mm was recorded

Fig 7 Deflection of Vertically corrugated beam

The final experimental values of ultimate load carrying capacities of all three beam specimens and their corresponding deflections are tabulated as shown in Table 1.

Table 1.Experimental results of Ultimate Loads and Deflections of Beam specimens

Model	Ultimate Load (KN)	Deflection (mm)
Beam -1	30	6.35
Beam -2	18	3.69
Beam-3	31	5.53

It is clearly denoted from the table 1 that the horizontally corrugated specimen with a spacing of 25mm (beam-2 specimen) is the least load bearing specimen and the load carrying capacity of the vertically corrugated specimen (beam-3) and the horizontally corrugated specimen without spacing (beam-1) has an increase of 60% in the ultimate load carrying capacity as compared to beam-2 specimen while the displacement is minimum in the beam-3 specimen as compared beam-1 specimen. Thus the experimental result concludes that vertically corrugated beam carries more load with minimum displacement as compared to other specimens.

4. NUMERICAL ANALYSIS RESULTS

The Numerical Analysis has been done by using the Abaqus software for all the three specimens that has been tested experimentally. The specimens

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were modeled respectively in the software with 1200mm span and were analyzed with simply supported end conditions under two point loading conditions. The software results are discussed individually which are as follows.

4.1 Back to Back horizontally corrugated beam without spacing (Beam-1)

The first specimen was modeled with the horizontal beam made of two horizontally corrugated channel sections fabricated back-to-back without spacing in between them. The sectional dimension of the specimen consists of an overall depth of 190mm with a flange width of 140mm and provided with a 25mm long lip at the ends of the flange. The beam is fabricated with a thickness of 2.5mm and for a span of 1200mm with a provision 45^{o} corrugation angle as shown in Figure 8. The software program was run and the analysis result was obtained with an ultimate load of 29KN corresponding to which a deflection of 4.2mm was arrived at the bottom mid-span of the beam.

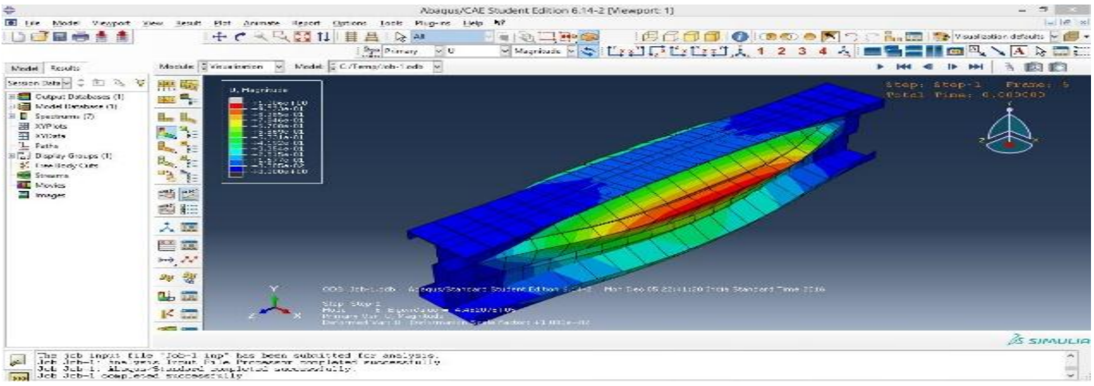

Fig 8 Numerical Analysis of Horizontally corrugated beam without spacing

4.2 Back to Back horizontally corrugated with Spacing (Beam-2)

This specimen was modeled similar to that of the previous beam made of two horizontally corrugated channel sections fabricated back-to-back but with a spacing of 25mm between them. Since the channels are separated with a gap of 25mm cover plates were modeled at top and bottom of the plate throughout the span of the specimen.

The specimen comprises of an overall depth of 190mm with a flange width of 165mm and with 25mm long lips at the ends of the flanges. The specimen is also provided with a 2.5mm thick cover plates at top and bottom for a width of 165mm throughout the span of the specimen. The overall span of the beam is 1200mm with 2.5mm thickness of the section and a provision of 45^{o} horizontal corrugation as shown in Figure 9.An ultimate load of 14 KN with a corresponding deflection of 3.98mm was obtained as a result of running the software program for the modeled specimen at the bottom mid-span.

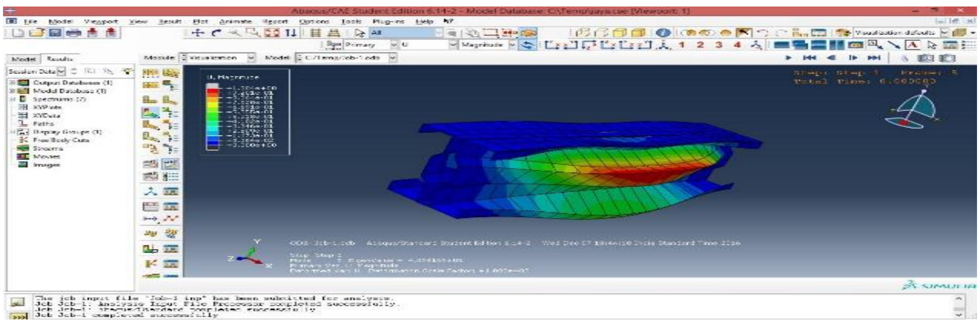

Fig 9 Numerical Analysis of Horizontally corrugated beam with a spacing of 25mm

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4.3 Beam with Vertical corrugation (Beam-3)

This specimen is modeled entirely with vertical corrugation throughout the span of the specimen. The sectional dimension of the specimen consists of an overall depth of 190mm with a flange width of 140mm and provided with a 25mm long lip at the ends of the flanges. The beam is corrugated for an angle of 45^{o}, with a thickness of 2.5mm and for a span of 1200mm as shown in Figure 10. The software program was run and the analysis result was obtained with an ultimate load of 41KN corresponding to which a deflection of 3.63mm was arrived at the bottom mid-span of the beam

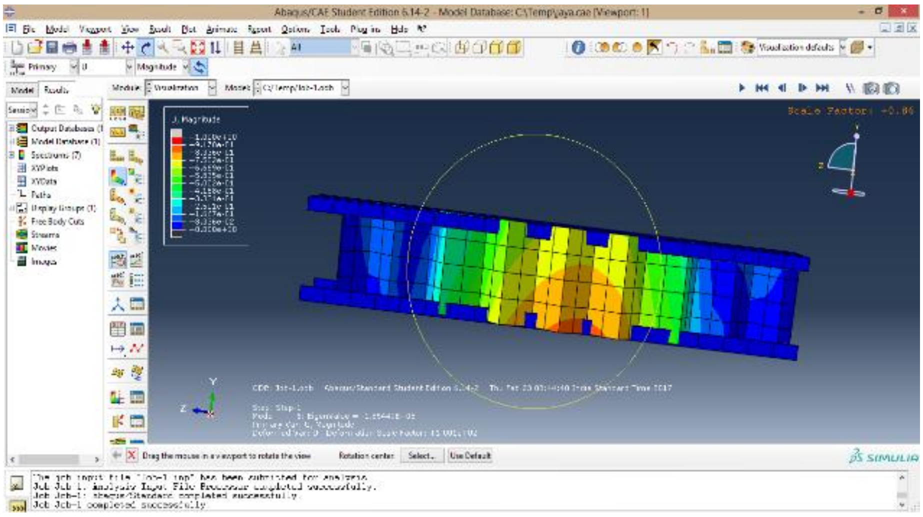

Fig 10 Numerical Analysis of Vertically corrugated beam

The final Numerical Analysis values of ultimate load carrying capacities of all three beam specimens and their corresponding deflections are tabulated as shown in Table 2.

Table 2.Analytical results of Ultimate Loads and Deflections of Beam specimens

MODEL	Ultimate load (KN)	Deflection (mm)
Beam -1	29	4.2
Beam -2	14	3.98
Beam -3	41	3.63

It is clearly denoted from the table 2 that the horizontally corrugated specimen with a spacing of 25mm (beam-2 specimen) is the least load bearing specimen while the load carrying capacity of the horizontally corrugated specimen without spacing (beam-1) has an increase of 2 times the amount of ultimate load carrying capacity and the vertically corrugated specimen (beam-3) has an increase of 3 times the amount of ultimate load carrying capacity as compared to beam-2 specimen while the displacement is minimum in the beam-3 specimen as compared beam-1 and beam-2 specimens. Thus the Numerical Analysis result also concludes similarly to that of experimental test results that the vertically corrugated beam carries more load with minimum displacement as compared to other specimens.

5. RESULTS AND DISCUSSIONS

5.1 Beam-1(Horizontal corrugation without Spacing) Specimen:

The observed and recorded values of the experimental and analytical results of the beam-1 specimen were plotted in a graph with Load(KN) in Y-axis and corresponding deflection(mm) in X-axis and compared as shown in Graph-1 below

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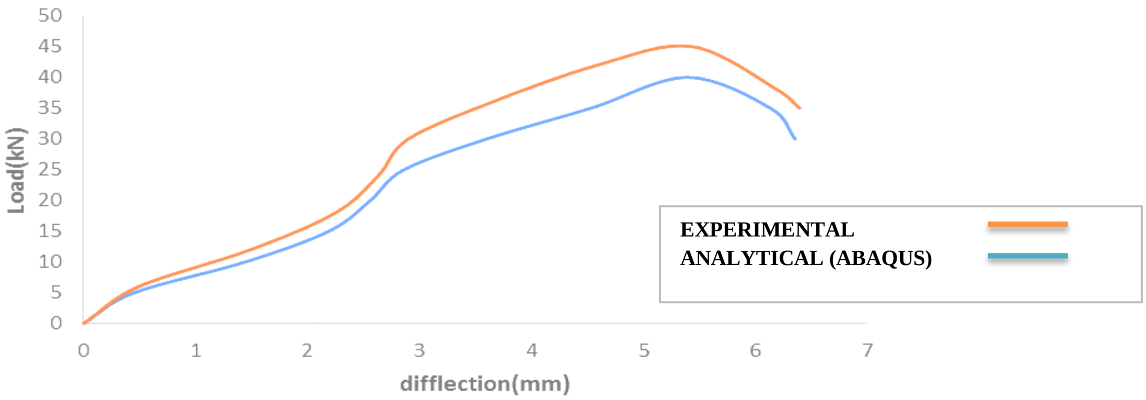
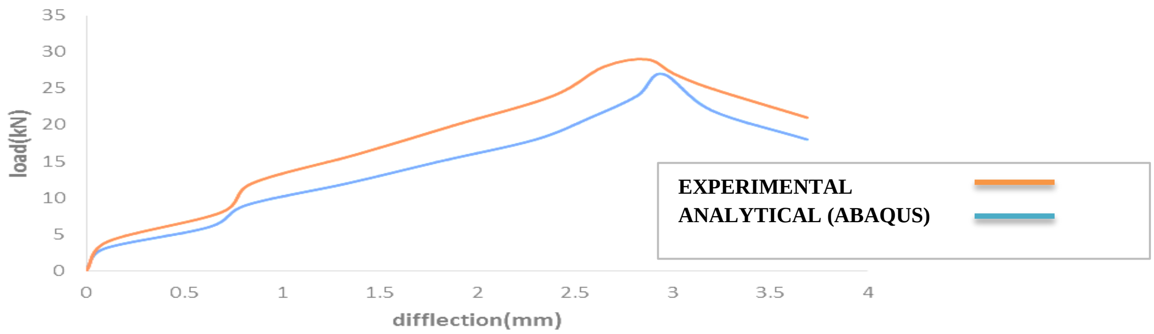


Graph-1 comparison of load vs deflection between experimental and analytical (abaqus) results.

The graph-1 clearly depicts that the load deflection curve for beam-1 specimen follows a similar path both in analytical as well as Experimental procedures. Due to the gradual application of loading at a uniform rate and practical conditions there has been a slight increase of 1KN in the experimental load of experimental procedure as compared to Analytical procedure.

5.2 Beam-2(Horizontal corrugation with a Spacing of 25mm) Specimen:

The observed and recorded values of the experimental and analytical results of the beam-2 specimen were plotted in a graph with Load(KN) in Y-axis and corresponding deflection(mm) in X-axis and compared as shown in Graph-2 below



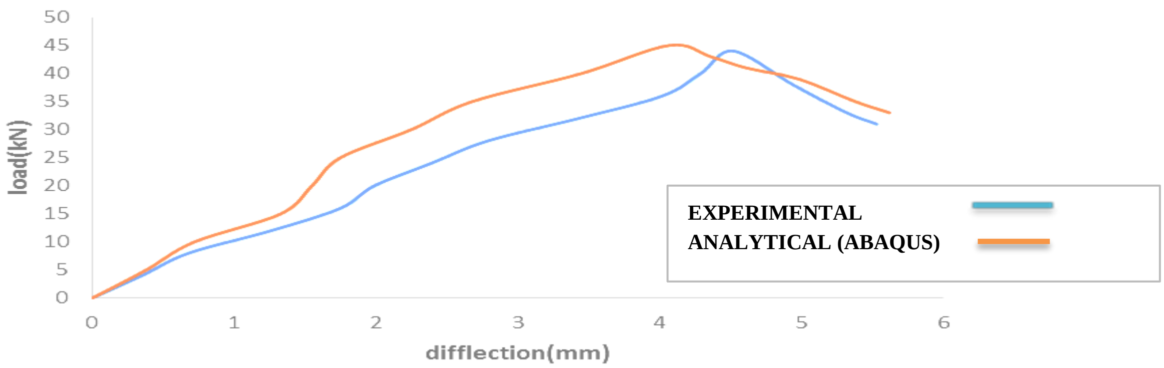
Graph-2 comparison of load vs deflection between experimental and analytical (abaqus)results

The graph-2 clearly shows that the load deflection curve for beam-2 specimen follows a similar path both in analytical as well as Experimental procedures which seems to be similar as that of beam-1 specimen. As that of beam-1 specimen, there was a slight increase in the experimental load value of 4 KN as compared to that of Analytical procedure. This increase is due to the gradual application of loading at a uniform rate and practical conditions at the laboratory.

As the spacing of 25mm is provided in this specimen the load carrying capacity is least as compared to that of other beam specimen due to the presence of the 25mm void throughout the span of the specimen.

5.3 Beam-3(Vertical corrugation) Specimen:

The observed and recorded values of the experimental and analytical results of the beam-3 specimen were plotted in a graph with Load (KN) in Y-axis and corresponding deflection(mm) in X-axis and compared as shown in Graph-3 below.



Graph-3 comparison of load vs deflection between experimental and analytical *(abaqus)results.*

The graph-3 clearly depicts that the load deflection curve for beam-3 specimen follows a similar path both in analytical as well as Experimental procedures. The vertical corrugation which has been provided acts as a web stiffener to the beam throughout the span pf the specimen. Due to the presence of this vertical corrugation it is noted that the ultimate load value obtained for beam-3 specimen (41 KN) is the highest value obtained as compared to all the other beam specimens.

6. CONCLUSION

The main objective of the project was successfully accomplished, from the experimental investigations carried out to study the flexural behaviour of cold-formed corrugated beam sections namely (i) horizontal corrugated back to back lipped channel sections without gap(beam-1) (ii) horizontal corrugated back to back lipped channel sections with gap (beam-2)(iii) vertical corrugated lipped channel sections by providing corrugation angle in horizontal and vertical direction sections(beam-3) and from the obtained results the following points has been concluded:

1. Vertically corrugated beam obtain a high resistance to the applied two point loading conditions and corrugation acts as a web stiffener for the beam.
2. The maximum load obtained were 41KN from the Abaqus result and 31KN from experimental test for vertically corrugated section for which corresponding deflection were recorded as 3.63mm and 5.53mm.
3. Other specimens namely horizontally corrugated specimens both with and without spacing were resisting the load nearly equal to half the value of load resisted by vertically corrugated beam both analytically and experimentally.

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