

# Experimental Behavior of Composite Beam using Hot Rolled Channel and Cold Formed Lipped Channel Section under Flexure



Pooja Podar, Gargi Rajpara

**Abstract:** Cold formed construction has widely recognized as an important contribution of saving in weight of steel as well as it can be formed according to strength requirements. Cold formed sections may have higher moment of inertia as compare to same weight hot rolled sections. Composite construction is usually associated with hot rolled sections especially I section, double C channel section considering high strength to weight ratio. The traditional hot rolled sections can be replaced by high strength cold formed sections considering its strength properties, less weight, easy fabrication and to fit demands of optimized design. This paper deals with experimental study of flexural behavior of composite beam using hot rolled as well as cold formed steel section. Two composite beams were casted using hot rolled ISMC 100 (back to back with spacing 50 mm) and Cold formed lipped channel section (back to back with spacing 50 mm). Experimental study conducted with simply supported loading conditions under two-point loading. Cold formed lipped channel section is pre-fabricated considering cold formed sectional properties given by EN 1993-1-3. Loading is given with load increment of 50 kN. Values of mid span deflection and slip at interface were recorded. The test strength of composite beam compared with design strength predicted by Eurocode standard.

**Key words:** flexural strength, cold formed composite beam, hot rolled composite beam, buckling.

## I. INTRODUCTION

Composite construction has important benefits by making steel and concrete work together, but these advantages can be improved if light weight cold formed steel sections are used instead of hot rolled sections. Large number of different configurations can be produced for cold formed sections to fit the demands of optimized design. Cold formed sections like lipped C-channel, Z purlin and welded I sections are already used for pre-engineered buildings. The main objective is therefore to explore innovative composite construction technology where light steel sections act compositely with in-situ concrete. Cold formed sections are light in weight and cost effective. Cold formed sections consisting of high strength and stiffness, more accurate handling, but having high depth to thickness ratio. The thinner section, easier the member can buckle.

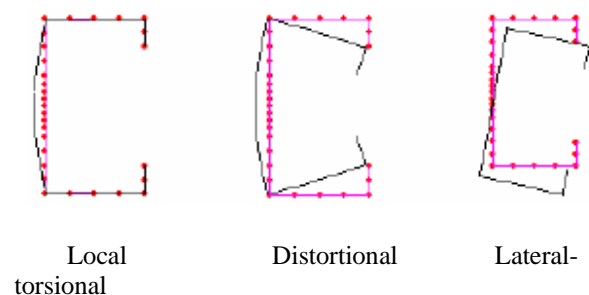
Cold formed sections, depending on the sheet thickness, can be susceptible to web crippling when subjected to concentrated loads. To increase buckling resistance, it is need to update shape of section or stiffening arrangement is required. Due to high depth to thickness ratio of cold formed section, different types of buckling modes are observed. Cold formed sections also involve some geometrical imperfections and residual stresses. Therefore, it is very important to look over some limitations of CFS sections and its solution. A sample comparison of same weight hot rolled and cold formed section is carried out as shown in Table :I

**Table-I: Comparison of sectional properties of cold formed and hot rolled section**

Section	W Kg	A cm <sup>2</sup>	h cm	I <sub>xx</sub> cm <sup>4</sup>	I <sub>yy</sub> cm <sup>4</sup>
ISMC 100 (t <sub>r</sub> = 7.50 mm) (t <sub>w</sub> = 4.70 mm)	9.2	11.7	10	186.7	25.9
CFS 115 (lipped C - channel) (t = 5 mm)	9.2	11.7	11.5	230.2	38.6

## II. BUCKLING MODES OF COLD FORMED LIPPED CHANNEL SECTION

There are three types of buckling modes can be observed for cold formed lipped channel as shown in Fig.1.



**Fig.1. Buckling modes of cold formed Lipped Channel**

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### III. LOCATION OF NEUTRAL AXIS OF COMPOSITE BEAM

NA is positioned as per resistance of concrete or steel offered against compression and tension. Location of plastic NA is as follows.

- Plastic neutral axis within concrete slab ( $R_c \geq R_s$ )
- Plastic neutral axis in flange of steel beam ( $R_c < R_s$  and  $R_c > R_w$ )
- Plastic neutral axis within web. ( $R_c < R_s$  and  $R_c < R_w$ )

### IV. ANALYTICAL MOMENT OF RESISTANCE

Moment of resistance in X direction and Y direction is calculated for CB1 and CB2. CB1 consisting of hot rolled ISMC 100 with 100 mm thick concrete slab. CB2 is consisting of Cold formed lipped channel section with 100 mm thick concrete slab.

Moment of resistance in X direction:

$$M_{plrx} = R_c \times (h_c/2 + h_p) + R_s \times h/2 - (R_s - R_c)^2/4 \times b_f \quad (1)$$

Moment of resistance in Y direction:

$$M_{plry} = R_c \times b_{eff}/4 + R_s \times X - (R_s - R_c)^2/4 \times b_f \quad (2)$$

Shear Resistance:

$$V_{pl,rd} = f_y \times A_v / \sqrt{3} \times \gamma_a \quad (3)$$

Where,

$$A_v = h \times t_w$$

$$R_c = 0.85 f_{ck} \times b_{eff} \times h_c / \gamma_c$$

$$\text{Where, } A_v = h \times t_w$$

$$R_c = 0.85 f_{ck} \times b_{eff} \times h_c / \gamma_c$$

$$R_s = A_a \times f_y / \gamma_a$$

For composite beam 1 (CB1) and composite beam 2 (CB2), two steel channels are placed at spacing of 50 mm. Moment of resistance and shear resistance are calculated using equation (1), equation (2) and equation (3).

Where :

A	Sectional area
W	Weight of section
h	Height of steel section
$b_f$	Width of flange
$t_f$	Thickness of flange
$t_w$	Thickness of web
$I_{xx}$	Moment of inertia in X-direction
$I_{yy}$	Moment of inertia in Y-direction
$M_{plrx}$	Moment of resistance in X-direction
$M_{plry}$	Moment of resistance in Y-direction
V	Shear resistance
$R_c$	Resistance of concrete slab
$R_s$	Resistance of steel section
$R_w$	Resistance of web
$I_{xx}$	Moment of inertia in X-direction
$I_{yy}$	Moment of inertia in Y-direction
$b_{eff}$	Effective width of composite beam
$p_y$	Depth of neutral axis
X	x ordinate of center of gravity
$h_p$	Height of profile deck
$h_c$	Thickness of concrete slab
$f_y$	Yield strength of steel

$\gamma_a$	Partial safety factor for steel
$\gamma_c$	Partial safety factor for concrete
$A_v$	Area of web
$A_a$	Area of steel section
CFS	Cold formed section

### V. CHECK FOR SECTIONAL PROPERTIES OF COLD FORMED SECTION (CFS 150)

CFS 150 is fabricated cold formed steel section. The weight to thickness ratio and other sectional properties are checked using EN 1993-1-3.

#### A. Basic Data

Total height of section  $h = 150 \text{ mm}$

Total width of flange in compression  $b_1 = 50 \text{ mm}$

Total width of flange in tension  $b_2 = 50 \text{ mm}$

Spacing between channels  $s = 50 \text{ mm}$

Steel core thickness  $t = 4 \text{ mm}$

Modulus of elasticity  $= 210000 \text{ N/mm}^2$

$c_1 = 15 \text{ mm}$  total width of edge fold (compression side)

$c_2 = 15 \text{ mm}$  total width of edge fold (tension side)

Web height  $h_w = 150 - 2 \times \text{thickness of flange}$

$$= 150 - 2 \times 4$$

$$= 146 \text{ mm}$$

Net width of flange in compression  $b_{p1} = b_1 - t$

$$= 50 - 4$$

$$= 46 \text{ mm}$$

Net width of flange in tension  $b_{p2} = b_2 - t$

$$= 50 - 4$$

$$= 46 \text{ mm}$$

Net width of edge fold in compression  $c_{p1} = c_1 - t$

$$= 15 - 4$$

$$= 11 \text{ mm}$$

Net width of edge fold in compression  $c_{p2} = c_2 - t$

$$= 15 - 4$$

$$= 11 \text{ mm}$$

#### B. Check for geometrical proportions

According to Euro code, EN1993-1-3 following criteria should be satisfied.

- $b_1/t \leq 60$  and  $b_2/t \leq 60$ ,

$$b_1/t = 146/4 = 36.5$$

$$b_2/t = 146/4 = 36.5 \quad \text{hence ok}$$

- $c_1/t \leq 50$  and  $c_2/t \leq 50$

$$c_1/t = 15/4 = 3.75$$

$$c_2/t = 15/4 = 3.75 \quad \text{hence ok}$$

- $h_w/t \leq 500$

$$h/t = 150/4 = 37.5$$

$$h/t = 150/4 = 37.5 \quad \text{hence ok}$$

- $0.2 < c/b < 0.6$

$$c_1/b_1 = 15/50 = 0.3$$

$$c_2/b_2 = 15/50 = 0.3 \quad \text{hence ok}$$

The influence of rounding of the corners is neglected if

- $c_p/t \leq 5$

$$c_{p1}/t = 15/4 = 3.75$$

$$c_{p2}/t = 15/4 = 3.75$$

Hence, all checks for geometric proportion of cold formed section are satisfied according to EN1993-1-3.

## VI. EXPERIMENTAL PROGRAM

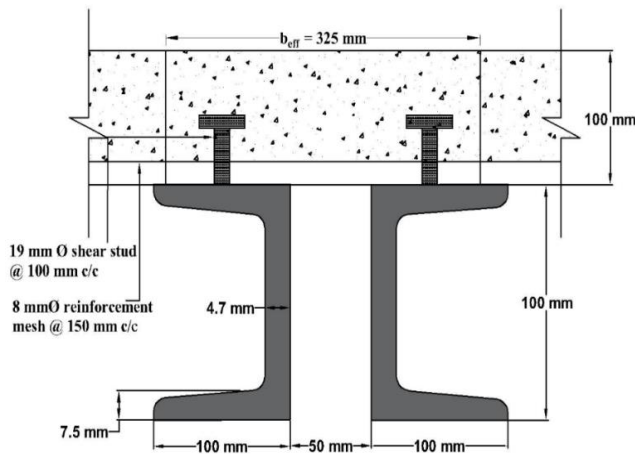
The two composite beams using hot rolled and cold formed Channel section have been constructed and tested. The parameter includes strength of steel and concrete and type of connection between steel beam and concrete slab are shown in Table II. The detailed geometry of test beams is shown in Fig.2 and Fig.3. The concrete slab and steel beam are connected by means of shear studs. Each beam has simply supported span of 1.2 m. The section size of steel beam includes slenderness ratio of flange and web falls under compact section criteria specified in Eurocode:4. Both specimens are designed with plastic method. Load frame set up for experimental program as shown in Fig.4.

**Table-II: Parameters of Test Specimen**

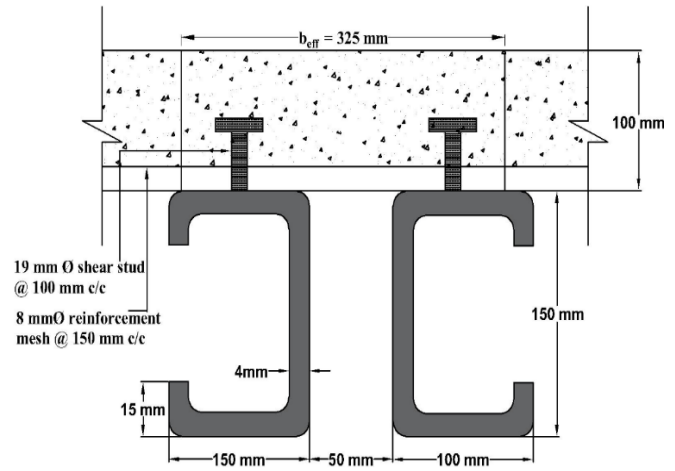
Beam Notation	Connection (Full/ Partial)	Yield Strength of steel (N/mm <sup>2</sup> )	Compressive strength of concrete (N/mm <sup>2</sup> )
CB1	Full	250	30
CB2	Full	250	30

**Table-III: Sectional properties of steel section**

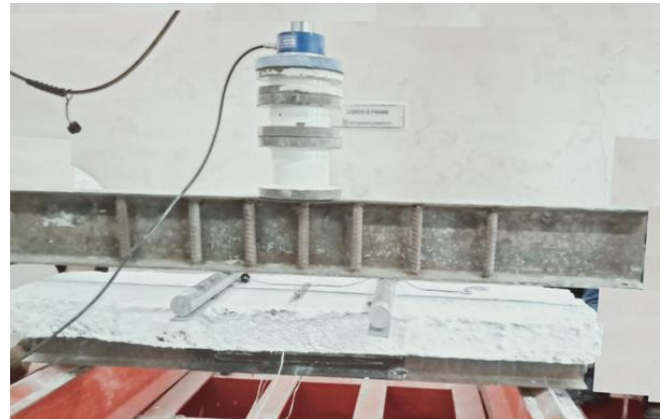
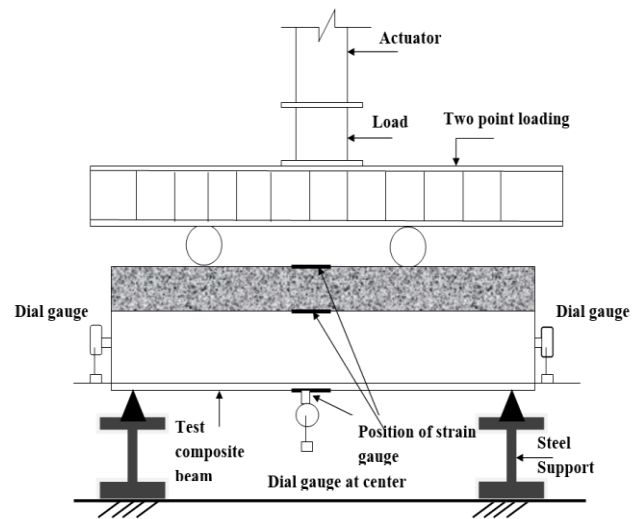
Section	Weight(kg)	Area (cm <sup>2</sup> )	I <sub>xx</sub> (cm <sup>4</sup> )	I <sub>yy</sub> (cm <sup>4</sup> )
2 ISMC 100	18.4	23.4	373.4	201.82
2CFS 150	16.57	21.12	346.99	195.16



**Fig.2. Composite Beam 1(CB1)**



**Fig.3. Composite Beam 2(CB2)**



**Fig.4. Experimental set up**

## VII. EXPERIMENTAL TEST RESULTS AND DISCUSSION

### A. Composite beam 1 (2 ISMC 100)

The composite beam-1 specimen consisting of 2 ISMC channel with spacing of 50 mm with full interaction between concrete slab and steel beam.

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A distribution spandrel beam with two-point loading placed at one third of distance from the supports as shown in Fig.4. The load was applied at a uniform rate from a 50-ton capacity load cell. Linear Variable Differential Transducer (LVDT) was attached at the bottom mid-span as well as at both sides of the specimen for measuring the mid span displacement and slip.

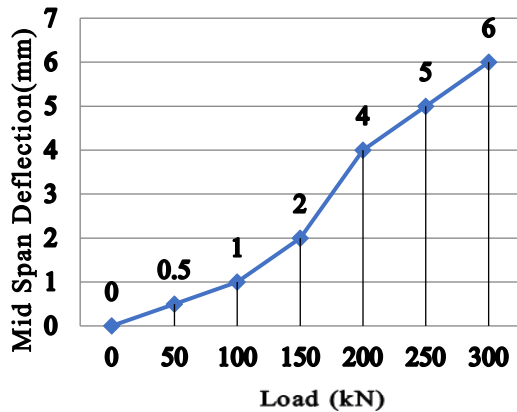


Fig.5. Load Vs Mid span deflection (CB1)

Table-IV: Mid Span Deflection (CB1)

Load (kN)	Mid span deflection(mm)
0	0
50	0.5
100	1
150	2
200	4
250	5
300	6

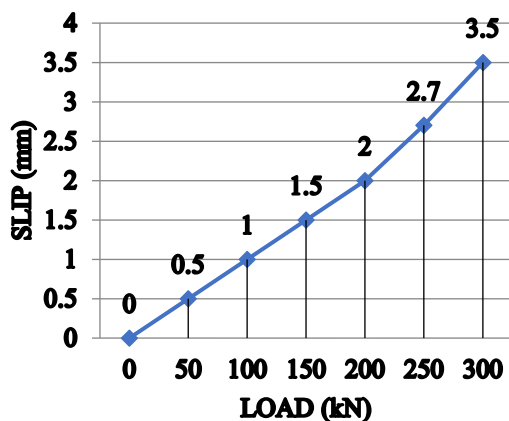


Fig.6. Load Vs Slip (CB1)

Table-V: Slip at interface (CB1)

Load (kN)	Slip(mm)
0	0
50	0.5
100	1
150	1.5

200	2
250	2.7
300	3.5

As shown in Fig.6, Fig .7 and Table –V, hot rolled channel shows limiting mid span deflection and slip includes very less buckling under ultimate load condition, which rebounds after releasing load.

## B. Composite beam 2 (2CFS 150)

The composite beam-2 specimen consisting of two cold formed lipped channels with spacing of 50 mm with full interaction between concrete slab and steel beam. Sectional properties of cold formed section are checked as specified before. According to depth to thickness ratio of Cold formed channel falls under class 2 (Compact section). Cold formed sections undergoes heavy deformations at ultimate load conditions. Cold formed composite beam reaches to plastic moment of resistance predicted analytically but it shows buckling of web near support, which shows deformation due to shear.

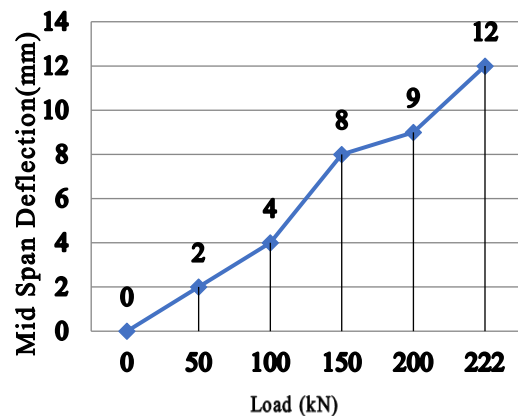


Fig.7. Load Vs Mid span deflection (CB2)

Table-VI: Mid Span Deflection (CB2)

Load (kN)	Mid span deflection(mm)
0	0
50	2
100	4
150	8
200	9
222	12

As shown in Fig.7 and Fig .9, cold formed lipped channel shows considerable midspan deflection and slip as compare to hot rolled section as well as it also involves more buckling under concentrated loading conditions as shown in Fig.8. Buckling mode of Lipped C Channel matches with distortional buckling mode as shown in Fig.1.





Fig.8.Distortional buckling of CFS section

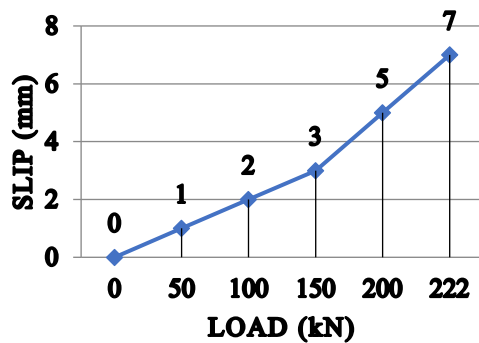


Fig.9. Load Vs Slip (CB2)

Table-VII: Slip at interface CB2)

Load (kN)	Mid span deflection(mm)
0	0
50	1
100	2
150	3
200	5
222	7

Table -VIII: Design strength and Experimental strength of composite beam

Composite beam	Predicted design strength (kN)	Experimental Strength (kN)
CB1 (2 ISMC 100)	250 kN	300 kN
CB2 (2 CFS 150)	180 kN	220 kN

CB1 (composite beam Steel section: 2ISMC 100) shows very less mid span deflection and slip as shown in Fig.5 and Fig.7. Buckling strength of Hot rolled channel is higher than cold formed lipped channel section. CB2 (composite beam steel section: 2 CFS 150) shows comparatively higher deflection as compare to hot rolled section. Composite beam 2 shows yielding of the cold-formed steel at the bottom of the composite beam. The slippage between the steel and concrete was recorded using dial gauges as shown in Fig.6 and Fig.8. Experimental strength of CB1 and CB2 matches with design strength predicted by Eurocode standard.

## VIII.CONCLUSIONS

The following conclusions can be drawn from the study into the behavior of cold-formed steel-concrete composite beams and hot rolled composite beam.

- 1) Cold formed sections consisting of high strength, stiffness as compare to hot rolled section. It is also important to look over limitations of cold formed sections, as it is susceptible of buckling under concentrated loading conditions.
- 2) CB1(hot rolled ISMC 100) shows a high flexural strength to the applied two-point loading
- 3) conditions as compare to CB2(cold formed CFS 150) as shown in Fig.5 to Fig.8.
- 4) Observed deflection is more in CB2 (Cold formed CFS 150) as compare to CB1(hot rolled ISMC 100).CB2 undergoes distortional buckling under two-point loading condition as shown in Fig.9.Cold formed composite beam undergoes higher deflection as well as deformation near support. Web buckles under ultimate load at support. It is need to provide bearing stiffener at support to avoid buckling of web.
- 5) Observed slip at interface under ultimate load conditions are 3.5 mm for CB1 (hot rolled ISMC 100(hot rolled ISMC 100) and 7 mm for CB2 (Cold formed CFS 150).
- 6) Cold formed composite beam can give comparable moment of resistance and design strength if some shape modifications is to be done or it also requires stiffening arrangement under concentrated loading conditions.
- 7) Analytical results of design strength match with Experimental testing as shown in Table III.

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