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Experimental Flexural Behavior of Composite Beam using Cold Formed Hollow Square Section

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***Abstract:** Structural hollow sections have excellent properties for resisting static loads, with regard to buckling, bi-axial bending and torsion. Structural hollow sections are generally used for truss components, considering greater stiffness and lateral strength. A square hollow section truss has about two third of surface area of same size I section. Hollow section truss may have smaller members as a result of higher structural efficiency. Construction of composite beam commonly includes I section. This paper deals with comparison of commonly used hot rolled or welded I composite section with cold formed hollow RHS and SHS composite section with respect to flexure and shear. Flexural tests were conducted to evaluate the structural behavior of the proposed composite beams. Two different steel sections were used for this study with nominal concrete strength of 30 MPa. The composite beams were tested under concentrated two points loading. The test results were plotted and compared with analytical results. The mid span deflections and slip were recorded for both composite beams. Buckling modes for both composite beams were identified. comparisons have been carried out between predicted beam strength as provided by Eurocode -4 and experimental test results. Sectional properties are checked for cold formed hollow square section using EN 1993-1-3*.

***Keywords:** flexural strength, Shear strength, deflection, slip, buckling modes.*

I. INTRODUCTION

Hollow structural sections are extremely versatile and they are used in various structural applications considering its strength to weight ratio. I sections gives greater moment of resistance along X direction but it gives very less moment of resistance in Y direction. Hollow sections give greater resistance against lateral forces and torsion considering its higher moment of inertia in Y direction. Design of hollow sections are based on yield; it shows heavy deformation under concentrated load.

Hollow sections give excessive deformation due to local buckling. Local buckling of square and rectangular cross sections is as under.Fig.1 shows local buckling of hollow rectangular and square section.

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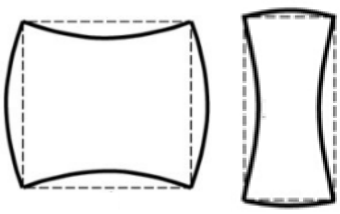

Fig.1. Local buckling of square and rectangular hollow section

II. ANALYTICAL CALCULATIONS FOR TYPICAL COMPOSITE BEAM

A sample comparison cases are taken in to account which shows comparison of flexural and shear capacity of composite beam using hot rolled section and cold formed section both. Calculation for moment of resistance in X direction and shear is determined using Eurocode-4.

(A).Typical Composite beam 1(Steel section: ISMB500)

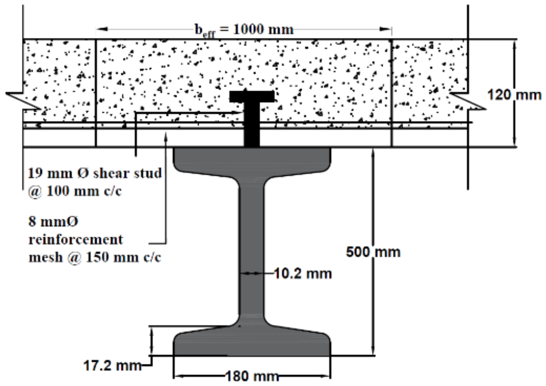

Fig.2.Typical composite beam 1

Moment of resistance in X direction and Y direction is calculated for all cases. For case 1, composite beam consisting of hot rolled ISMB 500 with 120 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:

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

Where,

$A_v=h\times t_w$

$R_c= 0.85 f_{ck} x b_{eff} x h_c/\Upsilon_c$

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$R_s= A_a x f_y/\Upsilon_a$

(B). Typical Composite beam 2 (Steel section: HYBOX 355)

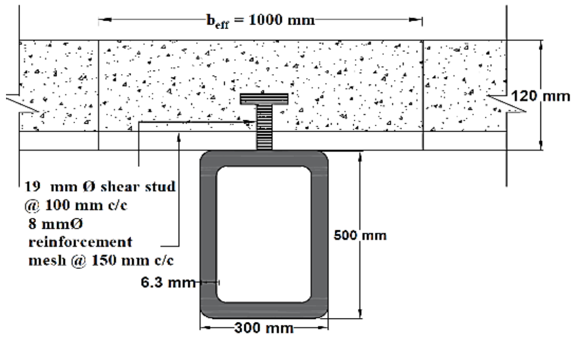

Fig.3.Typical composite beam 2

For composite beam 2, hollow rectangular steel section (cold formed) HYBOX 355 is used. HYBOX 355 is cold formed section manufactured by TATA steel, Europe (yield strength: 355 MPa).

Table: I Location of Neutral Axis for composite beam

Section	Location of Neutral axis
CB1	flange of I section
CB2	flange of Box section

Table: II Sectional properties of steel section

Section	Weight (kg)	Area (cm2)	I_{xx} (cm^4)	I_{yy} (cm^4)
ISMB 500	86.9	110.74	45218.3	1369.8
HYBOX 355	73.5	93.6	34346.0	15777

Table: I and Table II shows location of neutral axis of composite beam and sectional properties of steel section. HYBOX 355 gives very high moment of inertia in Y direction as compare to I section in spite of its less weight.

(C). Calculation for Moment of resistance and Shear: Composite beam -1 (ISMB500)

Span length L= 4000 mm

A_a= 11074 mm^2

t_w= 10.2 mm

t_f= 17.2 mm

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

Υ_c = 1.5 for concrete

Υ_a = 1.1 for steel

f_{ck} =30 N/mm^2

f_y=310 N/mm^2

b_{eff}=2× length of span /8

=2× 4000/8

=1000 mm

h_c= 120 mm

R_c =0.85 ×30×1000× 120 / 1.5× 1000

= 2040 kN.

$R_s = A_a \times f_y / \Upsilon_a$

= 11074 ×310 / 1.10×1000

=3120.85 kN

$R_w = f_y \times t_w \times (h - 2\times t_f)$

= 1398.61 kN

So here, $R_c < R_s$ and $R_c > R_w$, means neutral axis is located in flange of steel beam.

Moment of Resistance along X (Typical CB1)

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

= 1029.52 kN.m

Moment of Resistance along Y (Typical CB1)

Moment of resistance in Y direction is evaluated considering moment of composite section about Y axis.

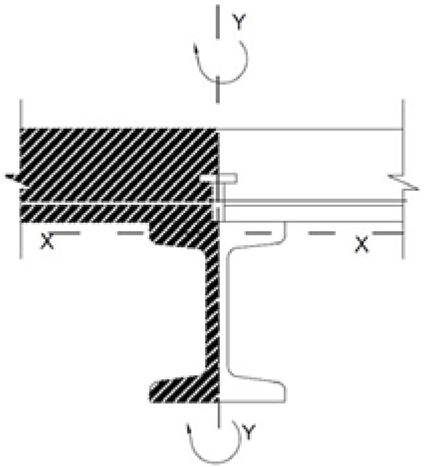

Fig.4.Moment of resistance composite section about Y axis

As shown in Fig.2, section is cut along Y axis, so half of composite section rotates about Y axis. So, moment of resistance in Y direction is determined considering the same aspect.

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

=299.83kN.m

$V_{pl,rd} = f_y \times A_v / \sqrt{3} \times \Upsilon_a$

=869.32 kN

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 stel
Υ_a	Partial safety factor for steel
Υ_c	Partial safety factor for concrete
A_V	Area of web
A_a	Area of steel section
SHS	Square hollow section
RHS	Rectangular hollow section

Table: III Moment of resistance and shear

Sr.No.	M_{xx} (kN.m)	M_{yy} (kN.m) (Composite beam)	M_{yy} (kN.m) (steel section)	V (kN)
Typical composite beam 1	1029.52	299.83	43.33	869.32
Typical Composite beam 2	1003.3	445.07	188.571	850.25

As shown in **Table III**, Lightweight cold formed sections are giving slightly less moment of resistance in X direction but shows considerable difference in moment of resistance along Y.

III. EXPERIMENTAL PROGRAM

Two beam specimens were casted with 100 mm thick concrete slab. The beam specimens were tested in a loading frame of 500 kN capacity load cell subjected to two-point loading as shown in Fig.5. The deflection of the beam specimens was noted down for every 50 kN intervals. The slip at interface of concrete slab and steel beam were recorded. The parameters of test beams are as shown in Table IV.

Table: IV Parameters of Test beam

	Steel section	**Yield Strength (N/mm^2)**	**concrete grade**	**Interaction (Full/ Partial)**
CB 1	**ISMB 175**	**250**	**30**	**Full**
CB 2	**SHS 150**	**210**	**30**	**Full**

Table: V Sectional properties of steel section

Section	Weight (kg)	Area (cm^2)	Ixx (cm^4)	Iyy (cm^4)
ISMB 175	19.30	24.62	1272	85
SHS (150×150×4)	18.01	22.95	807.62	807.62

Fig.5.Experimental set up

Table-VI : Limiting depth to Thickness Ratio of Hollow Square Section (BS EN 1-1:2005)

Class :II section	$\varepsilon = (235/ f_y)^{0.5} = (235/210)^{0.5} = 1.057$	
Part subjected to bending	c/t ≤ 83Ɛ	c/t = (h-3t)/t = (150-3×4)/4 = 34.5 83 Ɛ = 83 ×1.057 = 87.801 So it is ok.
Part subjected to bending and compression	c/t ≤ 38Ɛ	c/t = (h-3t)/t = (150-3×4)/4 = 34.5 38Ɛ = 38 ×1.057 = 40.166 So it is ok.

Hollow square section satisfies criteria of section classification class II as per Eurocode :3 Part 1-1. So depth to thickness ratio of hollow square section is within limit.

IV. RESULTS AND DISCUSSION

(A). Test Specimen 1(CB1):

The test specimen consisting of ISMB 175 with 100 mm thick concrete slab. Position of dial gauges is shown in Fig.5. Deflection and slip values were recorded as shown in Fig.7 and Fig.8.

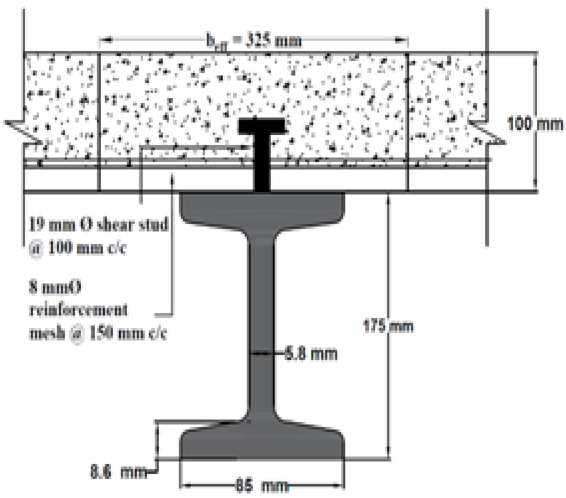

Fig.6. Composite beam 1 (CB1)

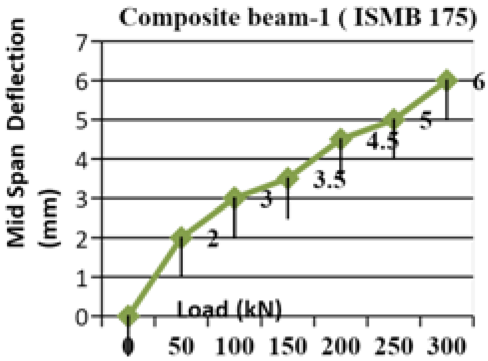

Fig.7. Load Vs. Displacement (CB1)

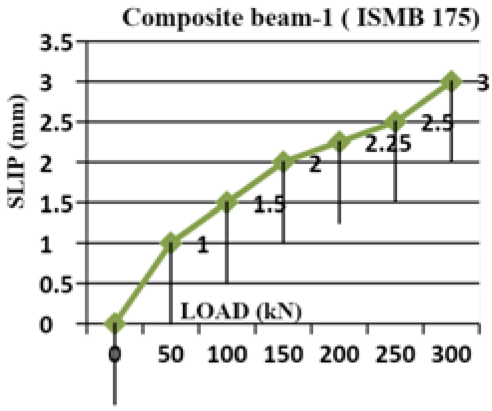

Fig.8. Load Vs. Slip at interface (CB1)

Table VII: Mid span deflection and Slip observed(CB1)

Load (kN)	Central deflection (mm)	Slip (mm)
0	0	0
50	2	1
100	3	1.5
150	3.5	2
200	4.5	2.25
250	5	2.5
300	6	3

Fig.9 Little buckling of flange at support

Fig.10 Minor cracks developed in slab

Fig.7 and Fig.8 shows mid span deflection and values of slip at interface for composite beam 1. It gives maximum deflection of 6 mm and slip value 3 mm under ultimate load conditions. As shown in Fig.9 little buckling of flange occurs at support. Minor cracks are observed in concrete slab as shown in Fig.10.

(B) Test Specimen 2(CB2):

The test specimen consisting of hollow square section 150 × 150 × 4 mm with 100 mm thick concrete slab. Hollow square section of yield strength 210 kN/m^2. Deflection and slip values were recorded for each 50 kN increment of load.

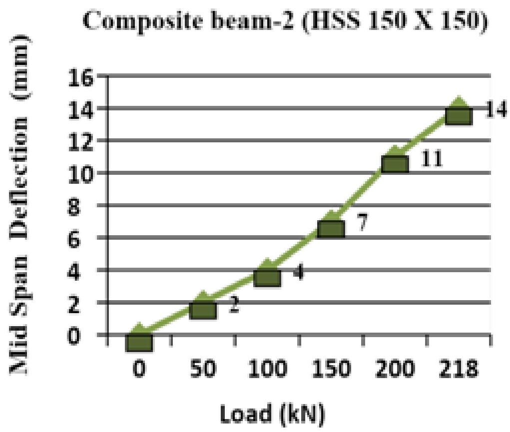

Fig.11 Composite beam 2 (CB2)

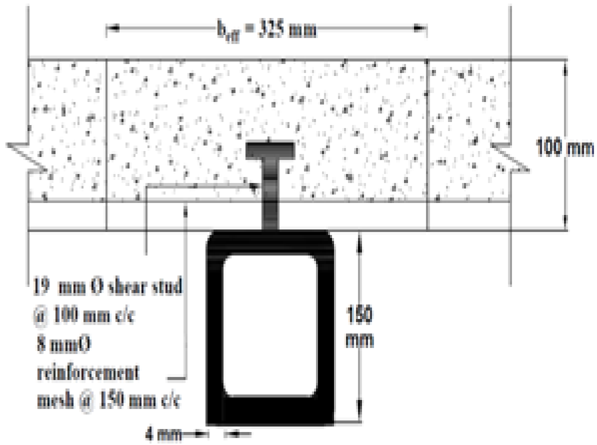

Fig.12. Load Vs. Displacement (CB2)

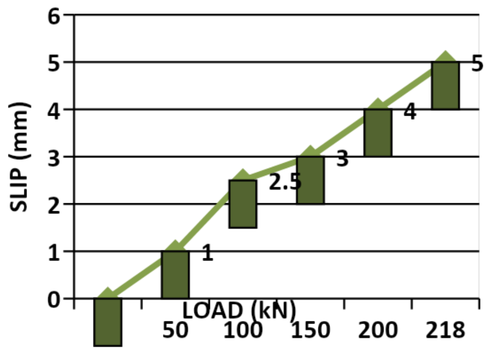

Fig.13 Load Vs. Slip at interface (CB1)

Table VIII: Mid span deflection and Slip observed(CB2)

Load (kN)	Central Deflection (mm)	Slip (mm)
0	0	0
50	2	1
100	4	2.5
150	7	3
200	11	4
218	14	5

Fig.14 Buckling of hollow section at support

Table VIII shows observed mid span deflection and slip at interface. CB2 (cold formed SHS 150) gives higher deflection and slip as compare to CB1 (hot rolled ISMB 175). Cold formed square hollow section shows buckling of web at support as shown in Fig.14. Cold formed section undergoes excessive mid span deflection due to buckling at support. At ultimate load condition considerable buckling of web occurs.

Table VIIII: Analytical and Experimental strength of beam

Composite beam	Predicted Analytical strength	Experimental strength	Remarks
CB1 (Hot rolled ISMB 175)	300 kN	310 kN	Buckling of flange and cracks in slab observed at 330 kN
CB2 (Cold formed SHS 150)	250 kN	220 kN	Considerable Buckling of web observed at 220 kN

V. CONCLUSION

- Structural hollow sections give greater moment of resistance along Y direction. A comparative study of Typical composite beam 1 (Hot rolled ISMB 500) and Typical composite beam 2 (Cold formed HYBOX 355) is carried out. Table III shows comparison of moment of resistance and shear capacity for both beams.
- Fig.7 and Fig.8 shows Mid span deflection and slip at interface for CB1 (Hot rolled ISMB 175). CB1 shows maximum mid span deflection of 6 mm and slip at interface 3 mm under ultimate load condition. Minor cracks in slab as well as little buckling of flange occurs beyond ultimate load (330 KN) as shown in Fig.9 and Fig.10.
- Fig.12 and Fig.13 shows Mid span deflection and slip at interface for CB2 (Cold formed SHS 150). CB2 shows maximum mid span deflection of 14 mm and slip at interface is 5 mm under ultimate load condition.

Excessive mid span deflection occurs due to buckling of web occurs before it reaches to ultimate load as described in Table VIIII

- CB2 (Cold formed SHS 150) shows considerable web buckling, although it satisfied limiting depth to thickness Ratio of hollow Square Section as per BS EN 1-1:2005. (Eurocode :3). CB2 shows buckling of web at support. The provision of depth to thickness ratio limits prescribed in BS EN 1-1:2005. (Eurocode:3) needs to be revised as section shows buckling at support.
- CB2 (Cold formed SHS 150) shows buckling of web at support only, so a stiffening plate can be provided at support (at beam to column Junction). As a result, total shear acting at support will be distributed between connecting plate and web of hollow square section and eliminates web buckling.

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