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Performance of Infilled Cold Formed Steel Channel Section Beams

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***Abstract*—The overall view of this paper is to study the behavior of cold formed steel channel section beams with an infill of concrete. The flexural behavior of cold formed steel infilled and hollow beams is investigated by conducting experimental study using two point load test [1]. Totally twelve beams are tested, out of which six are infilled with concrete and remaining six are hollow sections. Depth to thickness ratio is varied from 45 to 75 for all sections. For comparison, theoretical values are calculated based on Rigid Plastic Analysis for infilled beams and Australian/ New Zealand code 4600-2005 for hollow sections. Tremendous increase in load carrying capacity of infilled sections is observed. Using same amount of steel, high strength was attained by filling the sections with concrete. Experimentally it is observed that the load carrying capacity for infilled beams is not affected with a flat width ratio up to 71 for depth of section.**

Keywords—Flexural;Infilled beams;Hollow beams;Flat width ratio;Depth to thickness ratio;

I. INTRODUCTION

Composite construction refers to two load-carrying structural members that are integrally connected and deflect as a single unit. Slab and beam constructions are commonly used in bridges and buildings. Slab beam bonding is possible through the use of shear connectors welded. When the flange is in compression, the bond between the shear connector and the slab is assumed to be perfect. Cold formed steel members are cold formed in rolls or press brakes from flat steel which is not thicker than 12.5mm. Cold formed steel goods are made by working of steel sheet using stamping rolling or pressing to deform the sheet into a useable product [1, 9].

CFS sections are composed of thin plate elements which are highly prone to local buckling and this necessitates more sophisticated analysis and design procedures. In addition, more theoretical and experimental studies being conducted to capture the complex behavior when used in combination with concrete. The composite construction consists of providing monolithic action between prefabricated units like steel beams so that the two will act as one unit [2]. At the initial stages there will be natural bond between concrete and the steel. Shear connectors are provided to help the steel and concrete element to act in a composite manner ignoring the contribution made by the inherent natural bond towards this effect. Here the flexural behavior of cold formed steel channel section beams with an infill of concrete and hollow beams are investigated by conducting experimental study using two point load test.

II. INFILLED AND HOLLOW BEAMS

The theoretical studies related to concrete in-filled beams and hollow channel sections are carried out based on the rigid plastic analysis and Australian /New-Zealand code (AS/NZS 4600-2005) respectively [3]. The ultimate loads are found out from the known moment carrying capacity.

For analysis of infilled beams the following considerations are made.

Fy = yield strength of the steel
l = lip length
d = web of the section
b = bottom flange
t = thickness of the steel
r = radius
E = Young’s modulus of elasticity=2x10^5MPa
L = span of the beam.

For a beam,
Pc = force due to concrete
Pb = bond force
bc = width of the concrete
Nc and Ns = distances of neutral axis from the end of compression face for concrete and steel.
M = moment carrying capacity of the composite beam
ɣ = the reduction factor
d = the depth of the web
l = lip length
t = thickness of steel
fy = yield stress of the steel
fck = characteristic strength of concrete.

The equilibrium of forces in concrete, the distance from the neutral axis is obtained from the equation.

$$Nc = \frac{P_b}{(0.85\gamma fckbc)}$$

where γ = reduction factor= *0.85-0.007(fck-28)*

The equilibrium of forces in the steel, the distance from the neutral axis is obtained from the equation.

$$Ns = \frac{(tfy(2d + bc - 2l) - P_b)}{4tfy}$$

The moment of forces on the top fibre, the moment carrying capacity M of the composite sections can be determined from expression.

$$M= t\, f_y\, (d^{2+} db_c - 2N_s^2) - 0.425\gamma^2 N_c^2 f_{ck} b_c - t^2 f_y$$

For complete interaction between steel and concrete

$N\,c = Ns = N$ and

$$P_b = \frac{0.85\gamma f'_c\, b_c t f y (2d + bc - 2l)}{0.85\gamma f'_c\, b_c + 4tfy}$$

For the analysis of hollow beams Australian/ New Zealand code (AS/NZS 4600-2005) [4] is referred for determining the moment carrying capacities. The following considerations are made for a hollow beam

i. Based on the initiation of yielding and
ii. Nominal section moment capacity

Fy = yield strength of the steel
l = lip length
d = web of the section
b = bottom flange
t = thickness of the steel
r = radius
E = Young's modulus of elasticity=2x10^5MPa
L = span of the beam.

To locate the neutral axis using effective width calculation 6 steps are carried namely

1. Determining the section capacity: The effective width (be) of stiffened elements is known from the equations
   For λ<=0.673: be= b
   For λ>=0.673: be=ρb
   where b= flat width of element
   ρ =effective width factor

   $$\rho = \frac{\left(1 - \left(0.\frac{22}{\lambda}\right)\right)}{/\lambda} <= 1.0$$

   $$\lambda = \frac{1.052}{\sqrt{k}} \frac{w}{t} \frac{\sqrt{f}}{E}$$

   By knowing the compression flange width, the Neutral Axis (Ycg) can be located assuming that the web is fully effective.
2. Stiffened elements with stress gradients **:** The stresses are calculated using the equations

   $$f1 = \frac{y\,(Ycg-r-t)}{Ycg}$$

   $$f2 = \frac{fy\,(h-(Ycg-r-t)}{Ycg}$$

   i) Stress ratio, $\Psi = \frac{f2}{f1}$

   ii) Plate buckling coefficient,

   k =4+2(1+Ψ)3+2(1-Ψ)

   iii) Plate slenderness factor , $\lambda = \frac{1.052}{\sqrt{k}} \frac{w}{t} \frac{\sqrt{f}}{E}$

   For λ<=0.673: be= b
   For λ>=0.673: be= ρb
3. Effective width for capacity : This can be determined as below
   i. The section member capacity, the effective width

   $$be1 = \frac{be}{(3-\Psi)}$$

   ii. For Ψ<=-0.236

   $$be2 = \frac{be}{2}$$
4. The moment of inertia (Ix) and the section modulus(Sx) : $Sx = \frac{Ix}{Y\,cg}$
5. The bending moment or the moment carrying capacity: $M = S_x f y$
6. Ultimate load P(kN): $P = \frac{M * 2}{a}$

III. EXPERIMENTAL STUDY

Twelve specimens of two series are considered. Six hollow sections and six infilled sections. These specimens represent channel sections of length 1800mm [5]. Following two materials are used

1. Steel: The tension test has been conducted on the specimen to know the properties of steel sheet for conducting the tests. From the results of the tension test, the yield strength *Fy* of steel was found to be 205.2N/mm2.
2. Concrete: The concrete of grade M20 has been prepared using 53 grade ordinary Portland cement, coarse aggregates of 20mm size, natural river sand and portable water and used as an infill.

A. *Preparation and Procedure Of Testing Infilled And Hollow Specimens :*

The sheet was procured and it was cut into desired dimension and fabricated into desired dimensions as shown in Table 1. which is bent in cold condition [6]. The sheets were bent into desired shapes and lips were also bent using the press brake machine. The sections were painted externally for infilled beams and internally for the hollow beams. The specimens were kept for drying after painting. The concrete was poured from the open side. Both the sides were closed by steel sheet so that the concrete poured does not spill off out. The concrete poured beams were covered with wet gunny bags for 28 days. Shear connectors [7] are welded at a spacing of 150mm c/c for 600mm at both the ends and at the centre portion of the beam, spacing given is 300mm.

DESIGNATION	DESCRIPTION	
INFILLED BEAMS		
AI 1	1	250mm x 90mm
AI 2	2	250mm x 110mm
AI 3	3	250mm x 120mm
AI 4	4	250mm x 130mm
AI 5	5	250mm x 140mm
AI 6	6	250mm x 150mm
HOLLOW BEAMS		
AH 1	1	250mm x 90mm
AH2	2	250mm x 110mm
AH3	3	250mm x 120mm
AH4	4	250mm x 130mm
AH5	5	250mm x 140mm
AH6	6	250mm x 150mm

Table . 1 Designation and Description of Specimen

A loading frame of 100 tons capacity was used for testing the beams. Two point loads were applied at varying distances from the supports using a beam to provide a complete flexure area or bending area in the centre portion of the beam. Two roller supports were provided 50mm apart from the ends of the beam as shown in Fig 1. Load was applied gradually using a hydraulic jack till the failure of the beams [8]. The axial deformation is measured using the LVDT's (Linear Variable Displacement Transducers. Strain gauges of 350 Ω, 1.9 gauge factor strains were used. In this investigation strain gauges were attached to the composite beams and not for hollow beams.

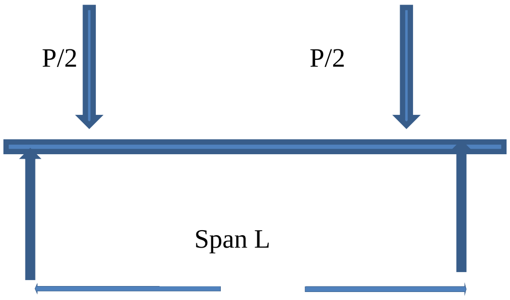

Fig 1. Placing of the supports and the loads

IV. EXPERIMENTAL RESULTS

Load deflection behavior of infilled and hollow beams are compared and discussed as shown in Fig .2 and Fig 3.There is linearity in the curves of in filled sections almost up to 55kN, later the curve followed a non-linear path up to the failure point. Whereas, the curves of hollow sections AH1, AH2, AH3 followed a linear path almost up to 15kN and then showed a non-linear path. The sections AH4, AH5, AH6 showed a linear path up to the failure point since these sections failed to resist the loads.

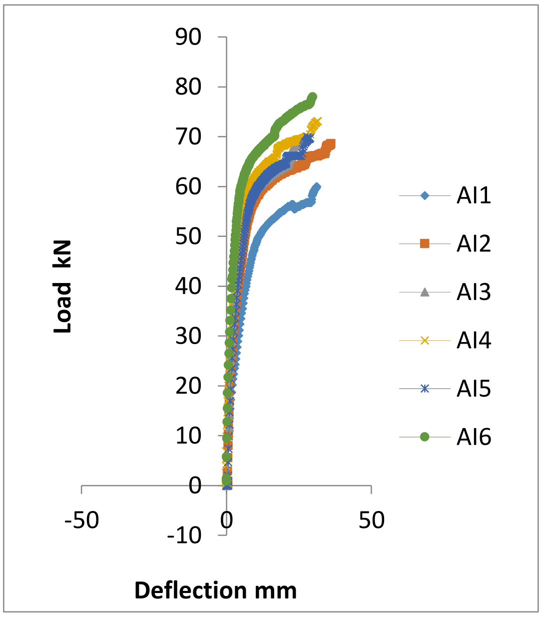

Fig 2. Load-Deflection curve for all the infilled beams

The curves of infilled sections were highly stiff than the curves of hollow sections. The average ductility index for all the infilled sections is 5.33 as shown in Fig 4.The composite interaction between the steel and the concrete increased the ductility index.

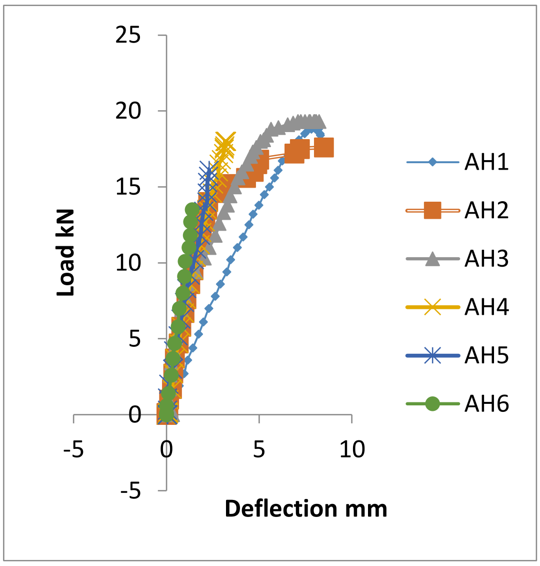

Fig 3. Load-deflection curve for all hollow beams

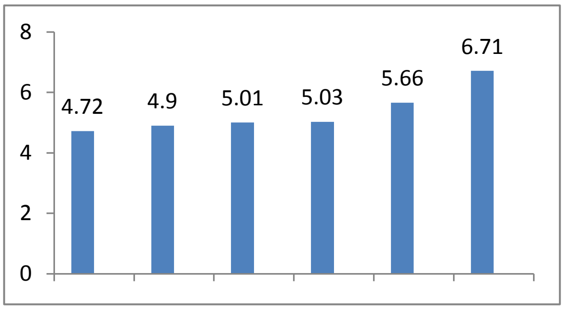

Fig 4 . Ductility of infilled beam

A. *Ultimate loads*

INFILLED BEAMS			
Name	P_{th}I in kN	P_{exp}I in kN	Pexp/Pth
AI 1	45.2	60	1.327
AI 2	48.53	70	1.4424
AI 3	50.13	73.3	1.462
AI 4	51.7	77	1.489
AI5	53.25	77.3	1.451
AI 6	54.77	79.2	1.446
HOLLOW BEAMS			
Name	P_{th}H in kN	P_{exp}H in kN	Pexp/Pth
AH 1	13.5	18.5	1.37
AH 2	13.09	19.2	1.4667
AH3	15.93	19	1.1927
AH 4	16.09	18	1.118
AH5	17.45	17.6	1.008
AH 6	18.18	16	0.88

Table 2. Theoritical and Experimental Ultimate Loads

It is observed from Table 2. that on an average, the ratio of experimental to theoretical loads (Pexp/Pth) was found to be 1.43 for infilled sections, whereas for hollow beams the ratio (Pexp/Pth) is 1.36 for sections AH1, AH2, AH3, but as the depth increased for the sections AH4, AH5, AH6 the ratio of experimental to theoretical decreased on an average of 1.

The Fig. 5 clearly indicates the decreasing of the ultimate loads as flat width ratio is increased. The sections AH1, AH2, AH3 had increase in ultimate loads since the flat width ratio was less than 60. Whereas the ultimate loads of sections AH4, AH5, AH6 decreased because the flat width ratio was more than 60.

It is observed from Fig 6 that as the flat width ratio is increased there is an increase in the ultimate loads of infilled to ultimate load of hollow section beams.

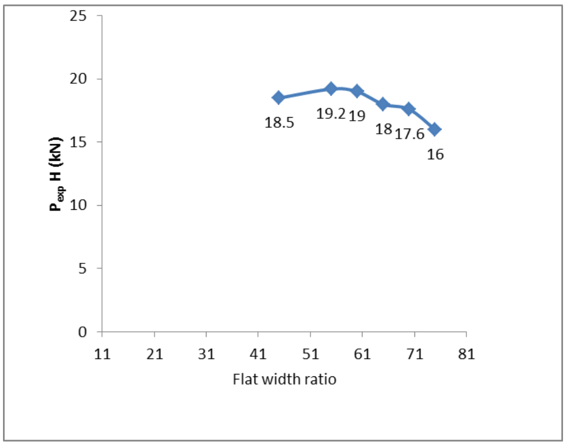

Fig 5. Experimental ultimate loads on hollow section- flat width ratio curve

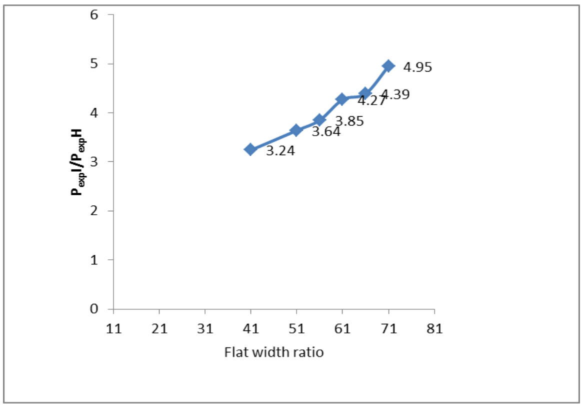

Fig. 6. Experimental loads of infilled and hollow sections- flat-width ratio curve.

B. *Strength To Weight Ratio*

Strength to weight ratio of the beams decreases with the increase in depth of the steel as shown in Fig 7. On an average the strength to weight ratio is found to be 4.73 for all the infilled sections.

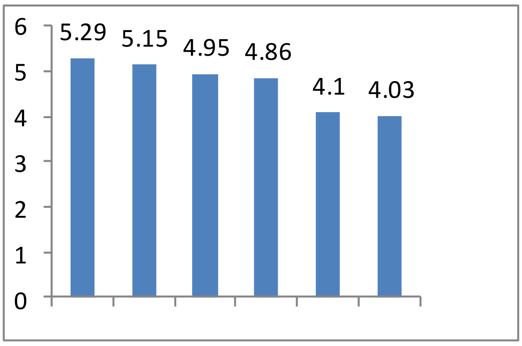

Fig 7. Strength to weight ratio of infilled beams

In general, it is observed that the moment carrying capacity and the rotational capacity increase with increase in depth of the section. Moment-curvature relation for infilled beams is shown in Fig 5 to Fig 11.

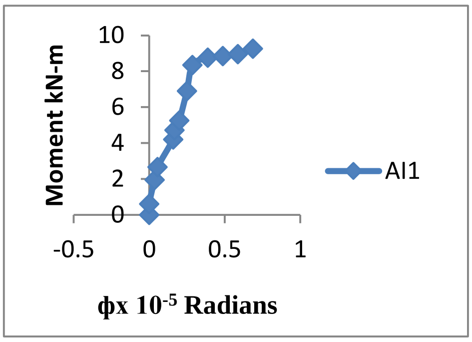

Fig 6. Moment –curvature curve of AI1

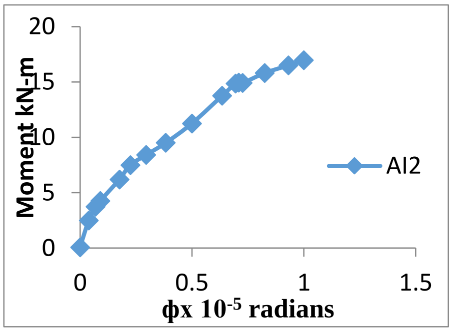

Fig 7. Moment- curvature curve of AI2

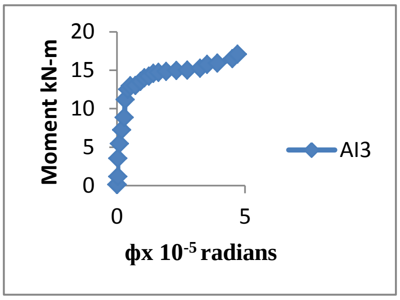

Fig 8. Moment- curvature curve of AI3

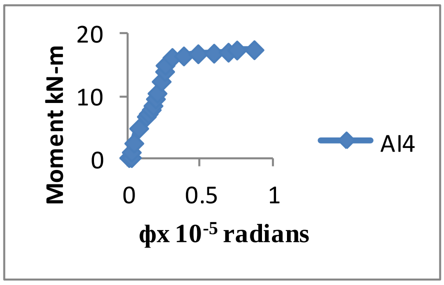

Fig 9. Moment- curvature curve of AI4

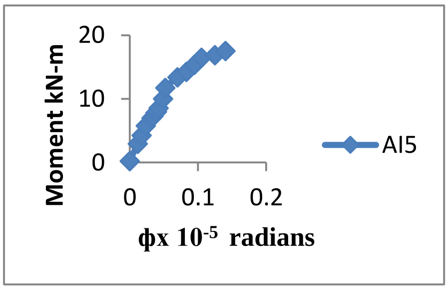

Fig 10 Moment- curvature of AI5

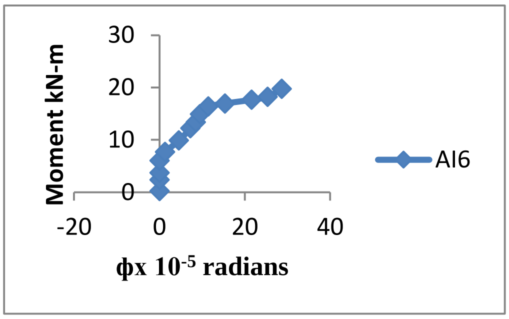

Fig 11. Moment- curvature curve of AI6

C. Failure Patterns

Failure was by buckling of the infilled beams where concrete in filled was easily separated from the steel section. Bending was also observed for all the infilled sections as seen in plate 1 and plate 2.It was noticed that in case of hollow beams, local buckling occurred in the compression zone. As seen in the plate 3 and plate 4 there occurred inward and outward buckling of the hollow beams and therefore it was end by the overall buckling.

Plate 1. Buckling of steel in compression zone

Plate 2.Separation of concrete and steel

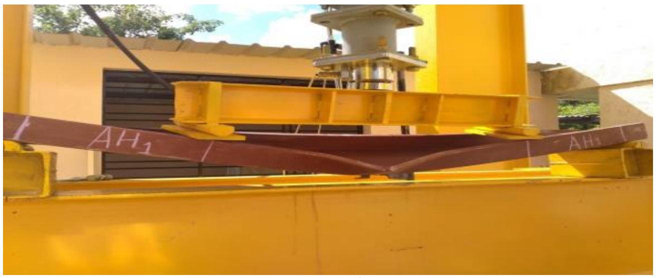

Plate 3. Buckling of steel inwards

Plate 4. Buckling of steel outwards and bending

V. CONCLUSIONS

The analytical results and the experimental results were observed and found that rigid plastic analysis can be adopted for determining the flexural strength. The experimental load carried by infilled beams with shear connectors showed tremendous increase in load carrying capacity. On an average it was found to be 74.09% more than the hollow beams. The load carrying capacity and the deflections are considerably poor with respect to hollow sections. Thus hollow sections showed poor performance on the application of load. The ratio of ultimate loads of infilled beams to hollow beams increased with increase in flat width ratio. The ultimate loads of hollow sections increased where the flat width ratio of depth portion is less than 60 and ultimate loads decreased when the flat width ratio of depth portion is more than 60.The average ductility index of infilled beams was found to be 5.33.The strength to weight ratio of infilled beams on an average was 4.7 for all infilled beams. The moment carrying capacity and curvature increased with depth of section. The failure of infilled beams was by cracking of concrete, separation of steel and concrete. The failure of hollow beams was by inward and outward buckling and bending of the specimens.

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