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Study on the Structural Behavior of Concrete Encased Steel Composite Members

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Abstract: This paper reports the findings of study that was undertaken to investigate the structural performance of the concrete encased steel composite members. These composite members provide an economical solution to structures requiring high strength and ductility and results in more sustainable construction as it reduces the usage of resources. The main parameters considered in this study are concrete compressive strength and the members with and without encased steel section. Theoretical and analytical studies were carried out and compared with the experimental results. The results indicated that concrete encased steel composite members provide a significant enhancement in the load carrying capacity, decrease in deflection and axial shortening when compared to reinforced concrete members.

Keywords: *Concrete encased steel composite member, FEM, axial shortening, deflection*

1. Introduction

Composite structures using steel and concrete are widely used in the construction industry for the past few decades. Generally concrete is stronger in compression and could withstand more compressive force and steel is stronger in tension. In composite construction the steel and concrete combined in such a fashion that the advantages of the both the materials are used effectively.[1] In the concrete encased steel composite members, steel beam (hot rolled steel section) is encased with concrete which provides fire protection to the steel member and also increases the overall stiffness of the section which in turn increases the load carrying capacity of encased steel members when compared with reinforced concrete section and leads to reduction in size of the section. Longitudinal and transverse reinforcement in the concrete encasement prevents excessive spalling of concrete under loading conditions.

Several works has been carried out in the past to study the behavior of concrete encased steel composite members. Ammar.A.Ali et al [2] investigated the structural behavior of concrete encased steel beam and concluded that the behavior of the beam is greatly affected by the steel beam core. The accuracy of the American Institute of Steel Construction (AISC) analysis methods in determining flexural strength of concrete encased members were studied by Chien chung chen[3]. He compared the analytical results from analyses performed with test data. Results from his study showed that the method of superposition of elastic stresses and method of plastic stress distribution on the steel section alone overly underestimated flexural strength of the concrete encased members. The composite action can be developed in encased composite members without shear anchors when sufficient confinement is provided by transverse reinforcement. To improve the ductility and meanwhile to ensure satisfactory corrosion performance, Xian li et al[4] studied the flexural behavior of GFRP reinforced concrete encased steel beams and they developed a new type of FRP – reinforced concrete encased steel (FRP – RCS) composite beams comprised of ductile structural steel shapes in combination with corrosion resistant FRP – reinforced concrete. The test results indicated that using encased steel shapes can provide a significant enhancement in load carrying capacity, stiffness, ductility and energy absorption capacity of tested beams.

Sherif El-Tawil et al[5] studied the strength and ductility characteristics of concrete encased composite columns. Concrete encased composite column design provisions of the American Concrete Institute (ACI 318), American Institute of Steel Construction – Load and Resistance Factor Design (AISC-LRFD) Specification, and the AISC Seismic Provisions are reviewed and evaluated based on fiber section analyses that account for the inelastic behavior of steel and concrete. Pedro R. Munoz et al[6] carried out experiments to test concrete-encased I-shape steel columns subjected to biaxial bending moments and axial compressive load in single curvature. The effects of the eccentrically applied axial compressive force, slenderness of the cross section and different material properties of concrete and steel, load-deflection and moment-curvature behavior on the maximum load capacity of a composite column were examined. The test results were compared with the analytical results of the maximum load capacity obtained from numerical analysis. K.Z. Soliman et al[7] assessed ultimate load of concrete encased steel short columns using various codal procedures such as Egyptian codes (ECP203-2007) and (ECP-SC-LRFD-2012), American Institute of Steel Construction, AISC-LRFD-2010, American Concrete Institute, (ACI-318-2008), and British Standard (BS-5400-5). The literatures revealed that the failure mechanisms of steel encased concrete structural members. In this study an attempt is made to study the load - deflection and load - axial shortening behavior of composite members with and without steel sections. Results show that composite members with concrete encased steel section and nominal reinforcement exhibit higher load carrying capacity and lesser number of cracks than reinforced concrete members.

2. Theoretical Study

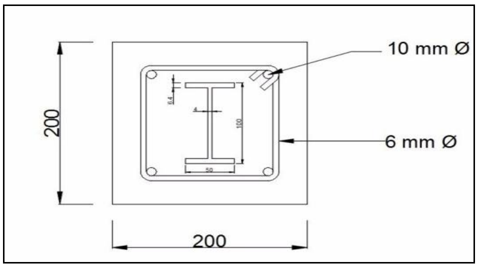
The theoretical study was carried out using Euro code 4[8] to find the load carrying capacity of the proposed concrete encased steel composite members. The details of the specimens are given in Table1.

Table 1: *Details of Specimen*

S. No	Specimen Details	Legend	Concrete Compressive Strength (Mpa)	Details Of Steel Section
1	Control Beam	B1	22.86	B
2	Concrete Encased steel beam	B2	22.86	A
3	Concrete Encased steel beam	B3	29.33	
4	Control Column	C1	22.86	B
5	Concrete Encased steel Column	C2	22.86	A
6	Concrete Encased steel Column	C3	29.33	

2.1 Specimen Description

The specimen encloses structural steel section, longitudinal reinforcement and transverse reinforcement. The 'I' shaped structural steel section used in the specimen is hot rolled section. Longitudinal bars are placed at each corners of the beam. The stirrups spacing is 100mm centre to centre and the adopted concrete cover is 40 mm as per EC4 recommendations. Figure 1, shows the cross section of the members.



TYPE A

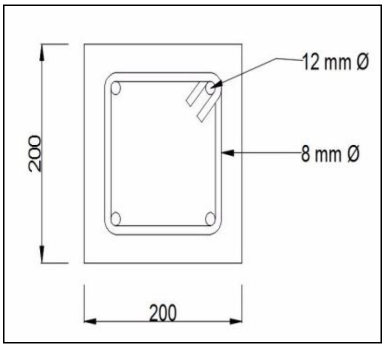


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Figure 1 *Cross section*

2.2 Material Properties

The 'I' section provided in the specimens is ISLB 100 @8kg/m, which comply with the standards in IS 808: 1989. The properties of concrete and reinforcement steel were given in the Table 2.

Table 2: *Material Properties*

Specimen	Young's Modulus (Mpa)		Tensile Yield Strength (Mpa)	Tensile Ultimate Strength (Mpa)		Compressive Ultimate Strength (Mpa)
	Concrete	Steel	Steel	Concrete	Steel	Concrete
B1	22360.67	2×10^5	250	3.5	415	22.86
B2	22360.67			3.5		22.86
B3	25000.00			3.13		29.33
C1	22360.67			3.5		22.86
C2	22360.67			3.5		22.86
C3	25000.00			3.13		29.33

2.3 Design Strength of Beam

The design strength of beam and column is calculated using Euro code 4 [8]. The position of neutral axis is calculated using the transformed area of steel (nA_s), where n is the ratio of modulus of elasticity between steel and concrete [$n = E_s/E_c$]

Position of Neutral axis

$$Y_n = (A_c y_1 + nA_s y_2)/(A_c + A_s) \quad (1)$$

Moment of resistance of

Concrete encased steel beam, $M_u = K_y E_c Ieq$ (2)

Rotation Component, $K_y = \varepsilon_y/(D - y_t)$ (3)

Where, I_{eq} – Equivalent moment of inertia [MOI of concrete + Transformed MOI of steel]
D is depth of the section, ε_y – Strain in steel.
Y_n – Neutral axis depth
A_c – Area of concrete
A_s – Area of steel

The deflection of the concrete encased steel beam due to the applied load is calculated using elastic analysis with the flexural stiffness of the composite section. The deflection for the design load for various cases of the beam is given in the Table 3.

2.4 Plastic Resistance of the Column Section

The plastic load for the concrete encased column is calculated using provisions given in Euro code 4.

$$P_p = \frac{A_a f_y}{\gamma_a} + \frac{\alpha_c A_c f_{ck\,cy}}{\gamma_c} + \frac{A_s f_{sk}}{\gamma_s} \qquad (4)$$

Where,

A_a – Area of steel section
f_y - Yield strength of steel section
α_c - 0.85
A_c – Area of concrete
$f_{ck\,cy}$ – Compressive strength of cylinder
A_s – Area of reinforcing steel
f_{sk} – Yield Strength of reinforcing steel
γ_a, γ_c and γ_s are partial safety factors.

3. Analytical Study

3.1 Finite Element Analysis

Finite element software is used to analyze the concrete encased steel sections. Beams and columns were modeled in ANSYS workbench based on the cross sectional details provided in the specimen description and the details given in Table 1.

Out of various analysis systems in the ANSYS workbench, Static structural is used to model the sections, meshing of the sections in to finite elements, solving and reviewing results. Material properties are given in the material table available in the ANSYS workbench and it is assigned to concrete encased steel members. The same material properties given in the Table 2 were adopted.

3.2 Modeling of Composite sections in Finite Element Software

The modeled composite beam and column is given in the figure 2 and figure 3 respectively. The beam is loaded with two point loads at a distance of L/3 from both the ends (figure 4) and the end condition is simply supported.

For the columns, axial load is given (figure 5) and their corresponding deformations, equivalent stress and strain were observed. The members were discretized and analysis was performed till the failure of the members.

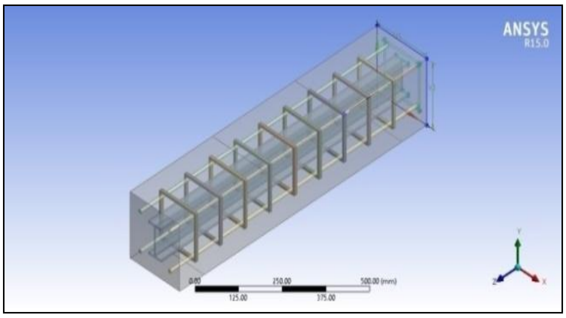

Figure 2 *Model of Composite beam*

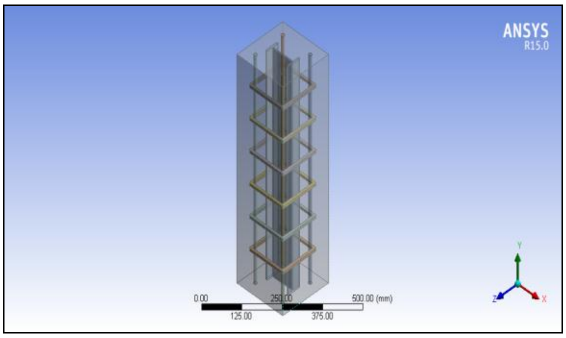

Figure 3 *Model of Composite column*

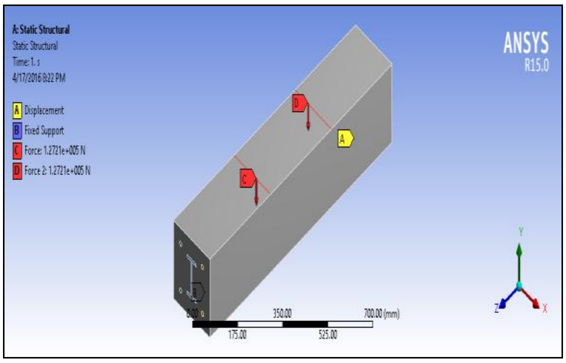

Figure 4 *Loading of Beam and Column*

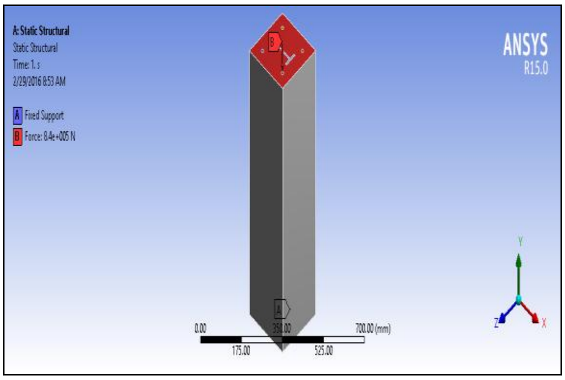

Figure 5 *Loading of Beam and Column*

4. Experimental Investigation

4.1 Details of Experimental Program

The specimens were cast according to the categories provided in the Table 1. Three specimens are cast in each category in order to obtain accurate results. The mechanical properties of concrete are given in table 6.

Table 6: *Concrete Properties*

Concrete Grade	Cube compressive Strength (MPa)	Cylinder compressive strength (MPa)	Split tensile strength (MPa)
M20(B1, B2)	22.86	16.48	3.13
M25(B3)	29.33	18.65	3.5
M20(C1, C2)	22.86	16.48	3.13
M25(C3)	29.33	18.65	3.5

4.2 Test Setup and Instrumentation

The loading setup for testing the specimen is shown in figures 6 and 7. A 50t capacity hydraulic jack is used to apply static load for beams. Calibrated load cell is placed below the jack to measure the applied load. Deflections were measured using displacement transducers and it was placed at the mid-section of the beam to observe the maximum deflection. Axial load is applied to the column using 100t universal testing machine. Load cell and transducer were connected to the computer via data logger which records the data's during the application of load and the data was recorded for every second during the loading period. Electrical strain gauges were used to measure the strain values.

Figure 6 *Test setup for Beam*

4.3 Test Procedure

The specimens are progressively loaded till the failure. The crack pattern exhibited by the specimen upon loading is observed and crack load is identified. The displacement transducer connected to the data logger measures the deflection of the beam corresponding to its load.

Figure 7 *Test setup for Column*

5. Results and Discussions

5.1 Failure Modes

At low loading level, all the specimens exhibited similar cracking behavior. As the load increased, the cracks formed in the mid span region and the shear span region propagated towards compression zone. In the specimen B1 flexural crack appears first at the load of 82 kN which is shown in the figure 8 and the cracks developed gradually with the increase of the load. In the specimens B2, B3 diagonal cracks appeared first at the load of 125kN and 135kN respectively, shown in the figure 9 and 10 which depicts the flexural failure and shear failure of the beams. Failure of the beam specimens B1, B2 and B3 occurs at the ultimate load of 188kN, 282kN and 293 kN. The column specimens showed the crushing of the concrete, when the load is increased progressively. Initially cracks appeared at the top face of the column upon further increase of load the encased concrete began to crush at the top face and spalled off. The first crack load of C1, C2, and C3 specimens are 239kN, 407kN and 489kN respectively and the specimens fails at the load of 496kN, 821kN and 883kN respectively. Figure 11, 12 and 13 shows the cracks in C1, C2 and C3.

In analytical study, the analysis is performed till the failure of the specimens. Typical failure modes of the beams and column specimens from the analytical results are shown in figures 14 and 15 respectively, which shows same behavior that was exhibited in the experimental study.

Figure 8 *Failure of B1*

Figure 9 *Failure of B2*

Figure 10 *Failure of B3*

Figure 11 *Failure of C1*

Figure 12 *Failure of C2*

Figure 13 *Failure of C3*

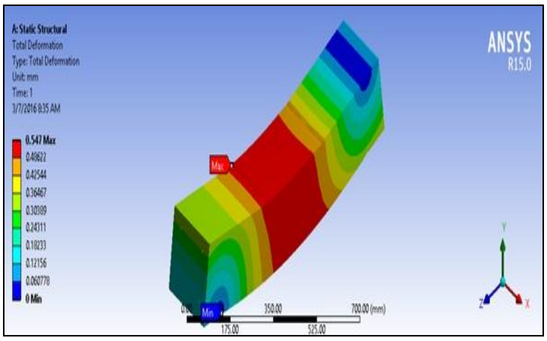

Figure 14 *Deformation in Beam*

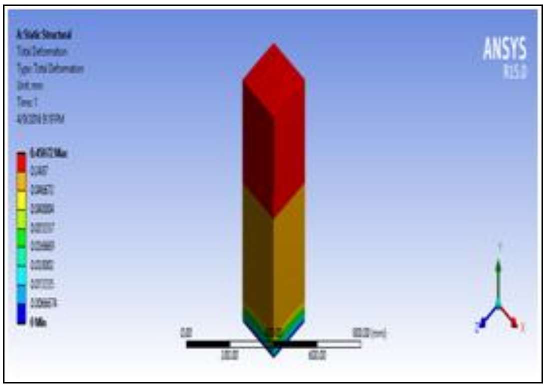

Figure 15 *Deformation in Column*

5.2 Load-Deflection Behavior

The load vs deflection curve was plotted for all the beams. B1 shows higher deflection when compared to the beams with concrete encased steel section. The load carrying capacity of the encased steel member is high due to the presence of encased steel section. From figure 16, it's depicted that the load carrying capacity of B2 is 52% higher than B1. Specimens B2 and B3 exhibit similar load deflection behavior but the load carrying capacity is increased by 11.5% and deflection of B3 is further reduced by 20% when compared to B2 which is depicted from the figure 17. The load carrying capacity of the B3 is higher than B2 is due to the impact of the increase in the compressive strength of the concrete.

Table 7: *Results of beam specimens*

Legend	Load (kN)			Deflection (mm)		
	T	A	E	T	A	E
B1	147.68	166	188	1.75	2.81	3.25
B2	225.72	253	282	0.297	0.348	0.554
B3	262.42	284	293	0.335	0.421	0.479

*T- Theoretical, A –Analytical, E – Experimental

5.3 Load - Axial Shortening behavior

From figure 18, it is observed that the load carrying capacity of the C2 is 63.5% high when compared with C1, due to the composite action between the concrete and the steel section. The effect of change in concrete grade increases the load carrying capacity of concrete encased steel column C3 by 8% than C2 and the axial shortening is reduced by 13%, which is depicted from the figure 19.

Table 8: *Results of column specimens*

Legend	Load (kN)			Axial Shortening (mm)		
	T	A	E	T	A	E
C1	446	490	496	0.563	0.582	0.597
C2	725	798	821	0.547	0.561	0.584
C3	785	863	883	0.459	0.468	0.512

*T- Theoretical, A –Analytical, E – Experimental

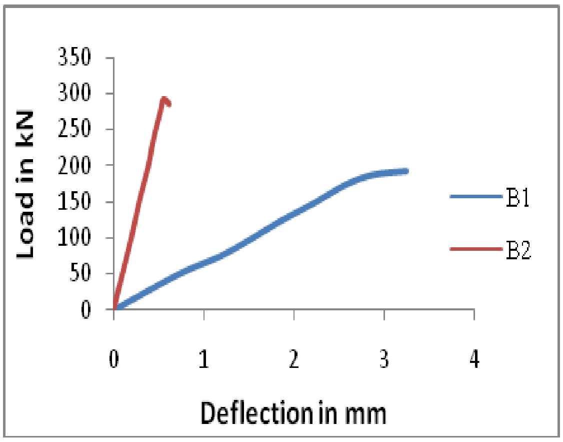

Figure 16 *Comparison of B1 and B2*

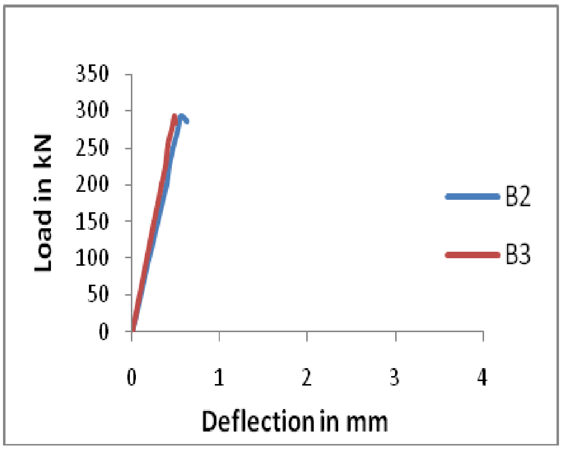

Figure 17 *Comparison of B2 and B3*

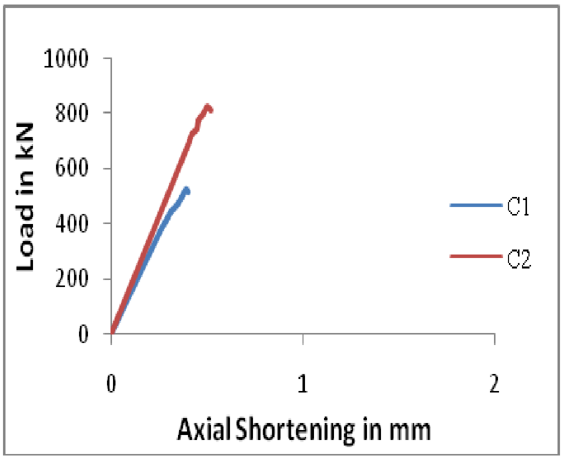

Figure 18 *Comparison of C1 and C2*

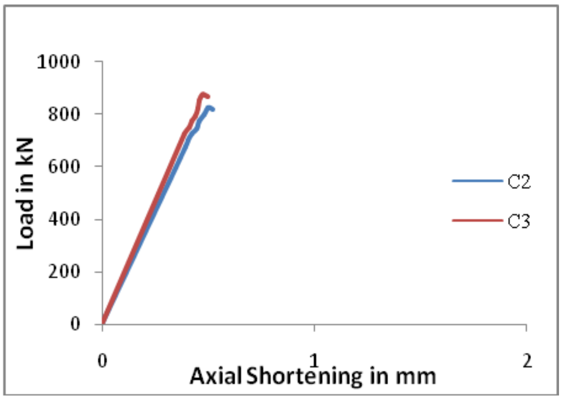

Figure 19 *Comparison of C2 and C3*

Conclusions

The study on concrete encased steel composite member gives better understanding of the structural behavior of composite members. From this study the following conclusions were made

1) Theoretical work and analytical work is carried out in addition to the experimental work to correlate the results. Analytical work is done using the finite element software.
2) The specimens B2 and B3 exhibits 1.5 to 2 times increased load carrying capacity than B1. The increased load carrying capacity is due to the presence of encased steel section and hence same cross sections can be used for higher loads.
3) Specimen B1 shows 75% higher deflection than the specimens B2 and B3, which interprets increase in stiffness of the concrete encased steel composite members.
4) Specimen B3 shows increased load carrying capacity by 11.5% than B2 and this can be manifested from graph.
5) The load taken by the concrete encased steel section C2 is found to be 63.5% higher when compared with C1.
6) Specimen C3 exhibits 8% increased load carrying capacity than C2.
7) Due to higher load carrying capacity and stiffness, the concrete encased steel composite members can be suitable for extreme loading conditions.

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