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Behavior of Steel Encased Composite Beams

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Abstract: This paper presents an experimental investigation of flexural behavior of steel encased reinforced concrete beams accompanied by a comparison with the results of the relevant finite element analysis. The experiments include three steel encased reinforced concrete beams and a reinforced concrete beam without steel profile. The experimental results were used to determine the flexural capacity of beams. Associate specimens of concrete cylinders and beams were tested for their strength. Failure of the encased beams is shown to occur progressively through a combination of bond-slip failure and local buckling of the steel sheeting. The flexural strength of the beam specimens has been computed by an model analytic and verified by a model of finite element analysis. The theoretical model based on a simple cross sectional analysis was shown to be in good agreement with the experimental data for the flexural capacity and also the finite element model for the calculation of flexural capacity is in good agreement with the experiments.

Key words: Composite beam, encased reinforced concrete, composite structures

Introduction

One of the most recent and important developments in steel, concrete and composite framed construction is the use of composite slabs that use steel decking consisting of profiled steel sheets as permanent form work for the concrete slab (Reinhold, 1976). This system has two major advantages: the profiled sheet is cheap and simple form of formwork that substantially reduces the site labor costs; and the profiled sheet can act composite with the reinforced concrete slab to increase the strength and stiffness and hence, reduce slab thickness. Extending the use of plain cold-formed steel sheets to the construction of reinforced concrete beams is the subject of this paper. It is envisaged that an open-box girder will be designed to span between the supports with the minimum additional restraints in order to reduce site labor costs and it will also be designed to act composite with the reinforced concrete section to reduce section sizes. After the concrete has set the section will then act composite with the reinforced concrete beam and this will be referred to as a steel-concrete composite encased (SCCE) beam. In the following sections, the behavior of composite encased beams is compared with reinforced concrete beams through experimental tests and theoretical analysis. The results show the use of composite encased beams will permit significant increases in span/depth ratios through increases in strength and stiffness.

Materials and Methods

The main aim of the experimental program was to study the flexural behavior of the SCCE beams. All the beams are of size 150 X 200 X 2500 mm. The SCCE beams (C1, C2 and C3) were fabricated using cold-formed steel troughs as the principal reinforcement. The other beam (R) was a conventional reinforced concrete beam.

Fabrication of trough

A 550 mm, wide and 2.5 m long cold-formed steel sheet is bent in the form of 150 X 200 mm-size trough of span 2.5 m. At the top of the trough 20 mm strips are provided at 200 mm c/c to act as bracing element using the same material and same thickness to avoid local buckling when the beam is loaded. The cold-formed steel trough is provided with L-Shaped shear connectors of 20X20X1.5 mm. The main purpose of using these shear connectors is to transfer shear between steel and concrete thus limiting the slip at the interface. The beam C1 and C2 were provided with 2 numbers of 6 mm diameter steel rods at top and bottom to take care of temperature and shrinkage effect. These beams were provided with 2 legged 6 mm diameter stirrups at 150 mm c/c. The shear connectors of width 20 mm is tack welded at a spacing of 200 mm c/c in the horizontal direction and 50 mm c/c in the vertical direction along the length of the beam in the side sheet and 750 mm c/c in the beam C1.In the beam C2, the shear connectors of same size, but of length 2500 mm is tack welded throughout the span of the beam at 50 mm c/c in the vertical direction in the side sheet and 75 mm c/c in the soffit. The beam C3 is same as C2, but without stirrups.

Casting of specimens

All the beams were casted for a mix ratio of 1: 2.5: 3.5 and water cement ratio of 0.48. Mixer was used to mix the concrete and compaction was given using needle vibrators. All the specimens were cast in one concrete pour so that their material properties could be considered to be identical. Along with the beams, standard concrete cylinders, cubes and plain concrete beams were cast. All the control specimens of concrete were tested for the determination of the strength and elastic modules. Steel coupon specimens were tested in tension to ascertain both the yield stress and the elastic modules of the cold -formed steel sheet and steel rods. The material properties for both concrete and steel are given in Table 1.

Table 1: Material properties

	Properties (N/Sq.mm)				
Material	$f`_c$	E_c	f_t	f_y	E_s
Concrete	30.2	0.28e5	3.057	-	-
Cold-formed steel sheet (1 mm)	-	-	-	18269	2.64e5
Steel rods (6 mm diameter)	-	-	-	293.55	1.99e5
Steel rods (12 mm diameter)	-	-	-	398	2.12e5

Test setup

The flexural beams were tested as simply supported beams of span 2.08 m with a constant moment region of length 0.65 m. Rollers and bearing plates were provided at each support and at the location of applied loads. The beams were tested to failure. The failure load and the experimentally determined bending capacities ME on the basis of failure load (Pu) for each beam are presented in Table 2.

Results and Discussion

It has been observed during the experimental investigation that before cracking the load is carried by both the steel sheet trough and concrete. As the load increases vertical separation is initiated at the location of load, the composite action is no longer maintained and the concrete is essentially carrying additional load. This process continued as more vertical separation, more load carried by concrete and more shear devices became disengaged. The second stage of failure reached when the additional load carried by concrete becomes sufficiently large to initiate a diagonal crack and finally the ultimate shear strength of the beam member was reached when the cracks become excessively large. The load - deflection response of the SCCE beams are shown in Fig. 1.

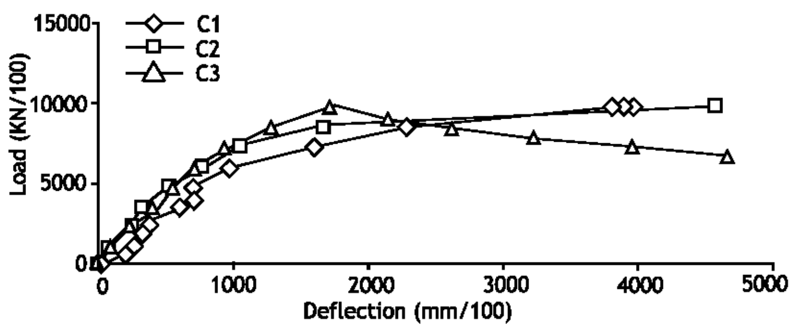

Fig. 1: Load versus deflection response of the beams (C1, C2 and C3)

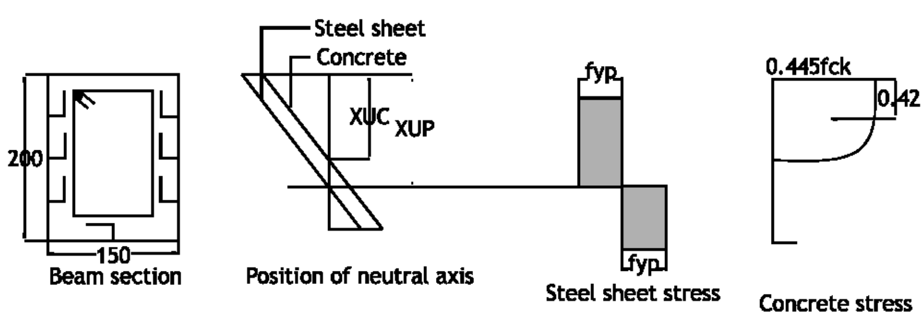

Fig. 2: Stress distribution in encased beams

Table 2: Comparison of moment

Beam designation	Failure load (KN)	Maximum Moment in KN.m		
		From experiment	From analytical model	Ratio (Mex./Man.)
C1-A	97	33.5	29.42	1.14
C1-B	99	34.2	29.42	1.16
C1-C	106	36.6	29.42	1.24
C2-A	86	29.7	27.93	1.06
C2-B	84	28.9	27.93	1.03
C2-C	90	31.1	27.93	1.11
C3-A	82	28.3	23.4	1.21
C3-B	79	27.3	23.4	1.17
C3-C	80	27.6	23.4	1.18
R-A	71	24.5	21.1	1.16
R-B	69	23.8	21.1	1.13

Flexural strength

The limit state design for reinforced concrete beams has been extended for designing SCCE beams, (Deric, 1993, 1994).

The basic equation for the flexural design of beams are developed assuming that the failure will occur by yielding of the tension steel followed by cracks developed in concrete. The flexural capacity (MT) of the SCCE beam section with partial shear connection can be determined by taking moments of the forces Fig. 2.

$$M_T = \phi[0.87 f_{ys} t(b.D + D^2 - X_{up}^2) + 0.87 f_y A_{st} d - 0.1512 f_{ck} b X_{uc}^2] \text{.......}(1)$$

In which Φ is the flexural capacity reduction factor = 0.9 The ultimate moment capacities MT for all the beams were computed on the basis of equation No. (1) and the results are tabulated in Table 2.

Finite element analysis

Finite Element Method is the most popular and widely used numerical method. With the usage of FEM, any structure having any shape and made of any material can be analyzed with a good degree of reliability. The commercial packages provide user friendly data input platforms and elegant and easy to follow display formats. One such package called ANSYS is used in this work. Three dimensional nonlinear finite-element models were developed to study the flexural behavior of SCCE beams using ANSYS. The structural solid family element of SOLID65 was used for concrete and SOLID73 was used for cold formed steel sheet. The boundary conditions for all finite element models are chosen to simulate actual conditions in the experimental setup. Load obtained from experiments was applied to finite-element model and the behavior was studied. The results from finite-element analysis are in good agreement with the experimental results. These results validate the finite element model.

An Experimental investigation was conducted to study the feasibility of using cold-formed steel sheets as permanent form work and tension reinforcement for the SCCE beams. Bending moment obtained for the SCCE beams are more than the conventionally used RCC beam of same capacity. The load deflection characteristics of the system show that a fairly ductile response was obtained with large deflections being achieved in the inelastic region. This system may be more suitable in the earthquake prone zones. A theoretical model based on a simple cross sectional analysis was shown to be in good agreement with the experimental data for the flexural capacity. A finite element model for the calculation of flexural capacity is in good agreement with the experiments.

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