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Flexural Strength of Composite Beams Partially Encased in Lightweight Concrete

[1]Issam M. Assi, [2]Serein M. Abed and [3]Yasser M. Hunaiti
[1]Civil Engineering Department, Al-Isra University, Jordan
[2]University of Jordan
[3]Civil Engineering Department, University of Jordan, Jordan

Abstract: The ultimate moment capacity of partially encased composite beams had been studied theoretically and experimentally. Tests were carried out on a total number of twelve beams of four different sizes with a constant length of about 2.0 m loaded by two points loading. Three groups, four beams each, were tested to investigate the contribution of different types of concrete to the ultimate moment capacity of partially encased sections. Eight of the simply supported beams were partially encased in lightweight concrete and normal concrete, four specimens each. The beams were tested under major axis bending to evaluate the ultimate moment capacity of such sections. The third group was tested as bare steel sections and the experimental results were compared with the partially encased beams. Theoretical values of the ultimate moment capacity of the tested sections were also included. The results of this study showed that the concrete contribution to the ultimate capacity of steel sections was significant. However, the use of normal concrete showed insignificant enhancement to the flexural strength of the tested composite sections when compared to lightweight concrete. The tested beams were capable of reaching moments in excess of the theoretical predictions and thus lightweight concrete may be considered as a reliable component to be used in composite construction.

Keywords: Composite, Beams, Lightweight Concrete, Steel, Partially Encased Beams Flexural Strength

Introduction

Composite construction may be considered as reliable choice attaining proper balance between the advantages it offers and the cost. Adoption of composite construction leads to the use of every material to its best advantages. Furthermore, comparing between steel and reinforced concrete structures on a side and composite structures on the other, composite structures have several advantages among which are; high strength to weight ratios, higher energy absorbtion and the possibility of using longer spans without encountering deflection problems.

There are several shapes of steel concrete composite beams such as encased beam, box beam, flangeless beam, castellated beam, and others. Full encasement is usually expensive in relation to the benefits obtained and therefore partially encased beams may lead to a better performance with reasonable cost, since they have the advantage of saving time and material. Referring to the literature and previous research it seems that partially encased beams received little attention. To accommodate this type of beams within the composite construction field in parallel with the other types, this study initiates a renewed interest directed toward partially encased beams. To study the general behavior of such beams in flexure, emphasizing the effect of concrete type, tests are conducted on beams partially encased in lightweight and normal concrete. For comparison, bare steel beams were also tested. To reflect the experimental results, analytical predictions using the column deflection curve method as well as design for-mulae are presented.

Encased beams have received little attention by researchers, and partially encased beams have not been studied before, except in a very limited number of studies. It is therefore became desirable to investigate the ultimate strength of such beams under major axis bending. Among several parameters likely to affect the ultimate strength, the present study is restricted to the effect of concrete type on the capacity of partially encased beams. This research is also aimed to providing new data on using lightweight concrete in composite construction.

Results and Discussion

A total number of twelve beams were tested under two-point load system as shown in Fig. 1. Eight beams were tested in an MFL Prufsystem testing machine of 400 kN capacity. The other four beams (with a predicted theoretical capacity which exceeds the ultimate capacity of the testing machine) were tested in a CONTROL machine of 700 kN capacity.

Steel beams of IPE sections (German Standards) were used. Prior to casting, the inside of each beam was wire brushed to remove any rust. Deposits of grease and oil were cleaned away. Actual dimensions were measured and listed in Table 1. Steel plates of 1.5 mm thickness were welded at the ends of the beams.

The twelve beams were tested in three groups under major axis bending. The first group consists of four beams with different cross sectional dimensions all encased in normal concrete designated NC. The second group designated LW consists of four specimens and same dimensions as the first group but lightweight aggregate concrete was used for encasement. The rest of the specimens were tested as bare steel beams.

Two concrete mixes were used in this investigation. Normal concrete mix with ce-ment, sand, fine and coarse aggregates in the proportions of (1: 1.5: 2) by weight and a water cement ratio of 0.5 was used in the specimens designated NC. While for the specimens designated LW, lightweight aggregates concrete mix of cement, sand and pumice with the ratios of (1: 0.45: 2.55) with expanded perlite (0.75 L/kg of pumice) and a water cement ratio of 0.5 was used. Details of the concrete mixes are given in Table 2.

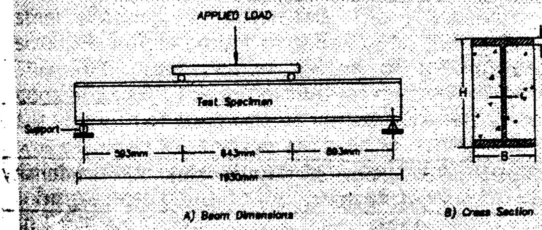

Fig. 1. Details of Tested Beam Specimen

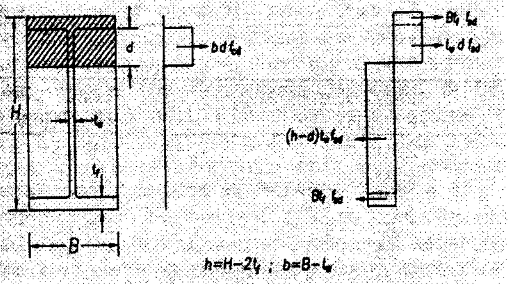

Fig. 2. Stress blocks for calculating M_{ux}

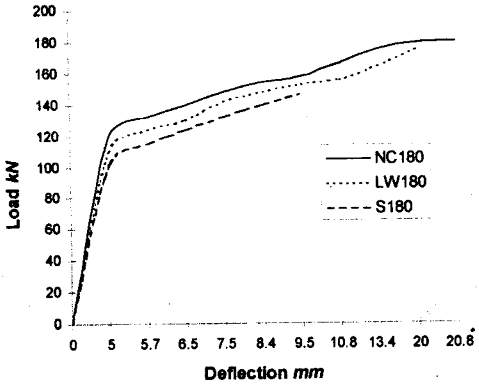

Fig. 3. Load Deflection Curve for IPE180

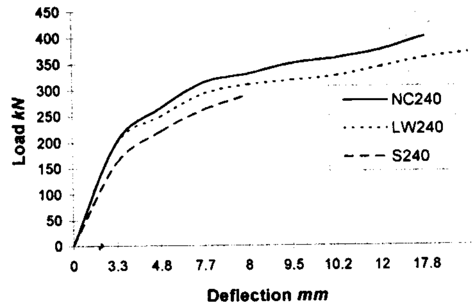

Fig. 4. Load Deflection Curve for IPE240

Three 150 mm cubes were prepared for each concrete mix to measure the concrete compressive strength. All compression specimens were cured for 28 days under the same conditions as the test specimens.

The beams were instrumented to measure loads, lateral and vertical deflections as well as strains in concrete. The load was applied monotonically and the desired measurements were taken during the load increments. Applied loads were recorded directly from the load indicator of the testing machines.

In addition to the built-in deflection measurement devices of the testing machines, three dial gages of 0.01 mm precision were used to measure both lateral and vertical deflections of the test specimens.

Demec gages were used for strain measurements. These gages were positioned in the middle of the beam in a variable number of rows according to the depth of the beam. Specimens were painted in white to monitor crack initiation and growth. The load level at which cracks initiate was recorded.

The ultimate moment of resistance can be calculated by establishing the $M\phi$ relationships of the cross section under consideration. Hamdan (1990), has developed a computer program to generate the $M\phi$ curves and to calculate the load carrying capacity of composite beam-columns in a general form to cover all possible shapes and contributions of materials. This program is extended and modified to calculate the beams capacities by the column deflection curve method (Hunaiti, 1997). Furthermore, Hunaiti and Abdel Fattah (1994), has derived a formula to calculate the ultimate moment capacity of partially encased sections based on full plastic analysis with rectangular stress blocks for both the steel and the concrete as shown in Fig. 2. The basic assumptions considered in calculating the moment capacity are:

- Steel is at yield for both tension and compression sides.
- Strain hardening is neglected in steel.
- Concrete in tension is cracked and thus ignored.
- Concrete above the neutral axis in compression reached the ultimate strength.

The ultimate moment of resistance for a partially encased section subjected to major axis bending as derived by Hunaiti and Abdel Fattah (1994), is given by:

$$M_{ux} = [Bt_f (H - t_f) - \frac{t_w}{2} d(H - 2t_f) + \frac{t_w}{2} (H - 2t_f)^2] f_{sd}$$

where d is the depth of neutral axis and is given by:

$$d = \frac{(H - 2t_f)\, t_w f_{sd}}{Bf_{cd} + t_w (2f_{sd} - f_{cd})}$$

Details of the design expressions for M_{ux} and the numerical procedure to generate the $M\ \phi$ curves together with the column deflection curve method can

Table 1: Standard Section Properties

Section and Beam Designation	section depth H: mm	area of cross section A: mm^2	flange thickness t_f: mm	flange width B: mm	web thickness t_w: mm	yield stress of steel f_y: MPa
IPE 180X91	180	2390	8.0	91	5.3	319
IPE 200X100	200	2850	8.5	100	5.6	318
IPE 240X120	240	3910	9.8	120	6.2	288
IPE 270X135	270	4590	10.2	135	6.6	313

Table 2: Details of Concrete Mixes

Concrete Type	Concrete mix	Average 28 day cube strength f_{cu}:: MPa	Average 28 day density pd:Kg/m^3	Fresh density pf: Kg/m^3
Normal weight	1: 2: 1.5/0.5 cement, coarse and fine aggregates	44.12	2235	2252
Light weight	1: 0.45: 2.55/0.55 cement, sand, pumice expanded perlite 0.7 l/kg of pumice	18.79	1790	1882

Table 3: Ultimate Loads and Corresponding Moments

BEAM Designation	Load at Failure P_e: kN	Moment at Failure M_e: kN m	Load at cracking P_{cr}: kN	Load ratio (P_{cr}/P_e)%
NC270	670	189.76	200	29.85
LW270	600	178.00	150	25.00
S270	365	108.28	-	-
NC240	415	123.12	100	24.10
LW240	400	118.66	90	22.50
S240	350	103.83	-	-
NC200	300	88.99	100	33.33
LW200	282	83.66	75	26.60
S200	238	70.56	-	-
NC180	245	72.67	75	30.61
LW180	220	56.30	75	34.09
S180	193	57.25	-	-

Table 4: Ultimate Moment Capacity of the Tested Beams

Beam	Experimental moment	Theoretical moment			Moment ratio	
Designation	M_e: kN m	M_{ux}: kN m	$M_{M\phi}$: kN m	M_e/M_{ux}	$M_{ux}/M_{M\phi}$	$M_e/M_{M\phi}$
NC270	198.7	159.55	161.17	1.25	0.99	1.23
LW270	178	153.19	154.31	1.16	0.99	1.15
S270	108.3	134.28	150.57	1.05	-	-
NC240	123.11	110.17	114.19	1.12	0.96	1.08
LW240	118.7	105.86	109.79	1.12	0.96	1.08
S240	103.8	93.3	106.81	1.11	-	-
NC200	88.99	73.44	47.79	1.21	0.98	1.19
LW200	83.66	70.61	71.61	1.18	0.98	1.17
S200	70.6	61.89	70.37	1.14	-	-
NC180	72.67	55.54	57.71	1.31	0.96	1.26
LW180	65.3	53.44	54.7	1.22	0.97	1.19
S180	57.25	46.43	53.78	1.34	-	-

be found in (Bazlamit, 1990; Hamdan, 1990; Hunaiti and Abdel Fattah, 1994).

The maximum strain reached by most lightweight concretes lies between 0.002-0.0025. For design purposes the INTERNATIONAL DRAFT CODE prescribes an ultimate strain of 0.0025 (CEB, 1977). In this study ultimate strains of 0.003 and 0.0025 were used for normal concrete and lightweight concrete, respectively. The experimental results demonstrated the predominant failure mechanism to be excessive yielding of steel and crushing of concrete accompanied by local buckling of steel flanges at stages very close to maximum load.

No significant differences in the behavior of the beam specimens have been observed. Hair line cracks begin at early loading stages. In almost tests, tension cracks were observed at loads around 25% of the failure load as shown in Table 3. Many of these cracks spread monotonically on both faces and widen as the load increased. Lightweight concrete sections behaved in a manner slightly different than normal concrete sections. Cracks number was less and they did not propagate in the middle third in a great number. Inclined cracks mainly under the points of load application were observed. No separation between steel and concrete was observed prior to failure, this confirms the composite action between the two materials.

The basic result which may be outlined that concrete presence significantly enhances the flexural strength of steel sections. Furthermore, the magnitude of the strength enhancement depends upon the section size.

Theoretical and design values of failure loads are compared with the experimental results, an increase in the strength of steel beams varied between 19 and 41% was obtained for section encased in normal con-crete.

On the other hand, lightweight concrete resulting in an increase in strength in the range of 14 to 27% as shown in Table 4.

Moreover, for partially encased beams of similar size the deflection for a given load was less than the corresponding value for bare steel section of the same size. This confirm that composite sections are stiffer and the concrete presence resulting in a substantial reduction in deflection values. Therefore, since normal concrete has a modules of elasticity twice that of lightweight concrete the stiffness of sections par-tially encased in normal concrete was higher than those with lightweight concrete. Hence the deflections observed in beams partially encased in normal concrete were less than those partially encased in lightweight concrete (Fig. 3 and 4).

Theoretical values of failure moments are compared with the experimental results as shown in Table 4, the ratio was found to be in the range of 1.05 to 1.34. The results showed that the tested sections behaved satisfactorily and the load carrying capacities were in excess of the theoretical predictions. Furthermore, the ratio be-tween the theoretical values obtained by the design formula and the column deflection curves was in the range of 0.96 to 0.99.

Notation

A	Area of steel section
B	Flange width
f_{cd}	Design strength of concrete
f_{sd}	Design strength of steel
f_y	Yield stress of steel
H	Section depth
L	Length of the beam
M_e	Experimental failure moment
M_{ux}	Ultimate moment calculated by formula
$M_{M\phi}$	Ultimate moment calculated by $M\phi$ curves
P	Applied load
P_{cr}	Load at crack initiation
P_e	Experimental failure load
t_f	Flange thickness
t_w	Web thickness

Conclusions

The following conclusions may be drawn from this investigation;

Regardless its type, presence of concrete significantly enhances the carrying capacity of the steel sections. However, concrete type is of little influence on the ultimate capacity of composite sections. Non appreciable reduction in the flexural strength of the tested composite sections was observed when lightweight concrete is used as an alternative for normal concrete. Therefore, lightweight concrete may be considered as a good choice for steel encasement providing both economy and strength.

Composite action between steel and concrete was confirmed in this investigation. Lightweight concrete can provide perfect bond to steel sections up to failure. The composite sections tested in this study were capable of reaching moment capacities higher than the predicted theoretical values, thus partially encased sections proved to be satisfactory and reliable.

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