International Journal of Civil and Structural Engineering
Volume 3 : Issue 3 [ISSN 2372-3971]
Publication Date : 30 December, 2016

STRENGTHENING STEEL I-BEAM WITH CONCRETE FLANGE

M.Rabie, W.Zaki and S.Zaky

Abstract—Strengthening and rehabilitation of structures is a major concern for researchers in the civil engineering community in recent years due to the aging of these structures and the need for effective methods of strengthening. Concrete slab can be used for strengthening existing steel beams, In this research, the behavior of composite beams was studied. An experimental program was carried out to test fourteen simply supported composite beams and a Steel I-beam without any concrete slabs. The composite beams were divided into three groups to investigate the strengthening of steel I-beam with a concrete flange with variable slab thickness, slab width and variable position of top steel I-beam flange to the concrete slab. A valuable conclusion help structural engineer in design of composite sections is gained.

Keywords— Strengthening, Concrete Slab, Steel I-beam, Shear Connectors, Composite Section.

I. Introduction

By combining steel and concrete it is possible to obtain the advantages of both materials working together. Therefore, from the materials strength point of view, it is possible to take advantage of the steel section to take tensile stresses and of the concrete in order to withstand compressive stresses. This combination results in high stiffness and smaller structural sections, gains in materials performance as well as reduced costs. Since natural bond may not be effective for composite action, several different types of shear connection systems are provided for the steel–concrete composite members to obtain the composite action. However, the full-composite action cannot be obtained since the steel–concrete composite members show partial-interaction behavior due to the deformation and slip at the interface under the applied loads.

II. Experimental work

An experimental program was carried out to test fourteen simply supported composite beams and a Steel I-beam without any concrete slabs. The composite beams were divided into three groups to investigate the strengthening of steel I-beam with a concrete flange with variable slab thickness, slab width and variable position of top steel I-beam flange to the concrete slab; all beams were supported on two edge supports to represent the case of simply supported beams, the concrete slab with dimensions 200 *B*T_S cm. with main reinforcement of 4 Φ10 mm. and secondary reinforcement of 5 Φ 8/m, as shown in figure and table (1).

Figure (1): reinforcement of tested composite beams

Table (1) Tested Specimens

Specimen	Details of Specimens				
Specimen no.1	Steel I-Beam without concrete slab				
	Specimen no.	Ts(cm)	B(cm)	A	
Group1 (5Specimens)	GB1.1	8	30	(1/3)Ts	
	GB1.2	8	30	(2/3)Ts	
	GB1.3	8	30	(1/2)Ts	Imbedded Length
	GB1.4	8	50	(1/2)Ts	
	GB1.5	8	30	Shear Connectors	
Group2 (5Specimens)	GB2.1	10	30	(1/3)Ts	
	GB2.2	10	30	(2/3)Ts	
	GB2.3	10	30	(1/2)Ts	Using Shear Conn.
	GB2.4	10	50	(1/2)Ts	
	GB2.5	10	30	Shear Connectors	P: Concentrated Load.
Group3 (4Specimens)	GB3.1	12	30	(2/3)Ts	Ts: Slab Thickness.
	GB3.2	12	30	(1/2)Ts	B: Effective Width.
	GB3.3	12	50	(1/2)Ts	A: Imbedded Length.
	GB3.4	12	30	Shear Connectors	

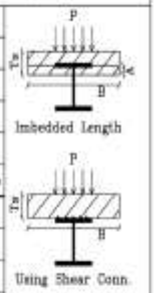

Table (2) Compressive Strength of Tested Specimens

The above results were the average of testing 3 standards concrete cubes.

Concrete Batch	Fcu kg/cm² (7 days)	Fcu kg/cm² (28 days)	Fcu kg/cm² (testing time)
1	288	437	455
2	280	381	410
3	295	452	465

Mohamed Rabie Mahmoud
Professor of Reinforced Concrete
Faculty of Engineering,Cairo University.
Egypt.

Wael Salah Eldin Zaki
Assistant Professor
Faculty of Engineering , Beni-Suef University
Egypt.

Soha Zaky Mohamed
Civil Engineering, Cairo University
Egypt.

III. Test Set-up and Loading Arrangement:

The specimens were tested under the effect of concentrated load arrangement. All beams were supported on two edge supports to represent the case of simply supported beams and the loads were applied by a hydraulic jack, the loading was increased by an increment equal to 0.5 ton as shown in figure (2).

Figure (2): Loading set-up.

IV. Measurements:

Different types of measurements were used during testing such as:

A. Loads :

The vertical loads were applied by a hydraulic jack and measured by a load Cell; the hydraulic jack and the load cell were calibrated before testing.

B. Concrete Strain:

Small steel plugs were used as a gage points for measuring concrete strain during test; they were fixed in their positions at the top surface of the concrete flange by means of an adhesive material as shown in figure (3).

A demic mechanical strain gage of 20 cm. length was used to measure the concrete strain.

Figure (3): Demic points arrangement.

C. Deflection:

Three LVDT with high accuracy were used for vertical deflection measurements. They were fixed at the bottom surface of the concrete flange as shown in figure (4).

Figure (4): Vertical deflection measurement.

D. Slippage:

A horizontal dial gage with 0.01 mm. accuracy was fixed at the end of the pre-slabs to measure the slippage between the concrete flange and the steel I-beam as shown in figure (5).

Figure (5): Horizontal dial gauges for slippage measurements.

V. Discussion of experimental Results:

Test results discussed here include mode of failure, cracking pattern, cracking and ultimate loads, maximum induced slippage, maximum deflection, deflection pattern, shear transfer along the interface area

A. Crack Pattern and Mode of Failure:

The initiation and pattern of cracks of the tested slabs can be explained as follows:

- **Steel I- Beam (Without Concrete flange)**

The Steel I-Beam was supported on two edge supports to represent the case of one way simply supported beam and subjected to concentric loading at mid span.

Increasing the load gradually on the steel I-beam till reached ultimate load of 4.4 ton as shown in figure (6).

Figure (6): Steel I-beam.

- ## *Composite beams:*

These beams subjected to concentrated loads as shown in figure (7).

Figure (7): preparation of beam GB1.1

The first crack was observed on the bottom surface at the section of maximum moment i.e. nearly to the middle of the span .After cracking load level, another bottom cracks appeared as the increasing of load as shown in figure (8).

Figure (8): Crack pattern of composite beam GB1.1.

The diagonal shear crack started to appear as the increasing of load, it was near the support. Increasing the load after the diagonal shear crack appeared led to increase in the diagonal shear crack width and initiation of new shear cracks between the two main diagonal shear cracks till the specimen had a complete shear failure as shown in figure (9).

Figure (9): Shear failure of composite beam GB1.1

B. *Cracking Load:*

Table (3) shows the values of the cracking load for the concrete flange. As the loading type concentrated, the first crack occurred at the bottom surface nearly to the mid span of the specimens at section of maximum bending moment.

From table (3), for composite beams it can be noticed that:

- Increasing the concrete slab thickness led to increase the cracking load because the improvement of the composite action.
- Increasing the width of the concrete slabs led to increase the cracking load compared with less concrete slab width.
- Increasing the interfacing area between steel I-beam and concrete slab led to increase the cracking load because the improvement of the composite action.

Table (3): Experimental Results of Tested Specimens

Specimen		Cracking load Pcr (ton)	Ultimate load Pult (ton)	Max. shear Qu (ton)	Shear strength qu (kg/cm2)
Group (1)	GB1.1	2.5	6.3	3.15	82
	GB1.2	2.7	7.4	3.7	96
	GB1.3	2.6	7.0	3.5	91
	GB1.4	2.9	7.7	3.85	100
	GB1.5	3.1	8	4	104
Group (2)	GB2.1	3	6.7	3.35	87
	GB2.2	3.6	8	4	104
	GB2.3	3.3	7.3	3.65	95
	GB2.4	3.8	8.5	4.25	110
	GB2.5	4.1	8.9	4.45	115
Group (3)	GB3.1	3.8	8.3	4.15	108
	GB3.2	3.5	8.0	4.0	104
	GB3.3	4	10.5	5.25	136
	GB3.4	4.2	10.2	5.10	132

C. *Ultimate Load:*

Table (4) shows the values of the ultimate load for both steel I-beam and composite beams and percentage of load increasing (using concrete flange). As the loading type was concentrated for all beams, it can be noticed that:

- The Ultimate load relative to tested steel I-beam increased by (43% to 52%) as the top slab thickness increased in case of top steel flange is at the bottom of slab thickness as shown in figure (10).
- The Ultimate load relative to tested steel I-beam increased by (75% to 238%) as the top slab width increased from 30 cm to 50 cm as shown in figure (10).
- The ultimate load of composite beams increased as the slab width increased. The ultimate load of composite beamGB1.3 with concrete slab thickness 8 cm and slab width 30 cm was about 90% of the composite beamGB1.4 with slab thickness 8 cm and slab width 50 cm.
- The ultimate load of composite beams increased as the impeded height between steel I-beam and concrete slab increased. The ultimate load of composite beam GB1.1 (top flange is at the bottom third of slab thickness) was about 85% of the composite beam GB1.2 (top flange is at the top third of slab thickness).

Table (4): percentage of load increasing (using concrete flange)

Specimen		Ultimate load Pult (ton)	Pult/Pc
Steel I beam (P_C)		4.4	1.00
Group (1)	GB1.1	6.3	1.43
	GB1.2	7.4	1.68
	GB1.3	7.0	1.59
	GB1.4	7.7	1.75
	GB1.5	8	1.82
Group (2)	GB2.1	6.7	1.52
	GB2.2	8	1.82
	GB2.3	7.3	1.66
	GB2.4	8.5	1.93
	GB2.5	8.9	2.02
Group (3)	GB3.1	8.3	1.88
	GB3.2	8.0	1.82
	GB3.3	10.5	2.38
	GB3.4	10.2	2.31

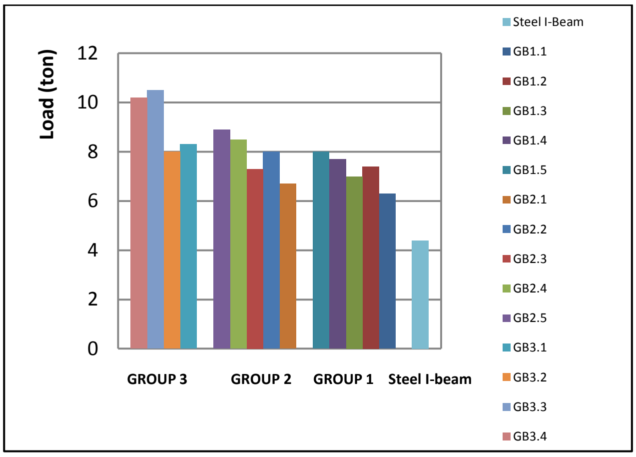

Figure (10): Ultimate Loads

D. ***Shear Transfer Along The Interface:***

Table (3) and figure (11) shows the average shear strength q_u values which calculated at the ultimate load. From these results it can be noticed that:

- The shear strength of tested steel I-beams increases as the slab thickness increase. The shear strength of tested steel I-beam GB1.3 with 8 cm slab thickness about 88% of the tested steel I- beam GB3.2 with 12 cm slab thickness.

- The shear strength of tested steel I-beams increases as the slab width increase. The shear strength of tested steel I-beam GB3.2with 12 cm slab thickness and 30 cm slab width was about 76% of the tested steel I- beam GB3.3 with 12 cm slab thickness and 50 cm slab width.

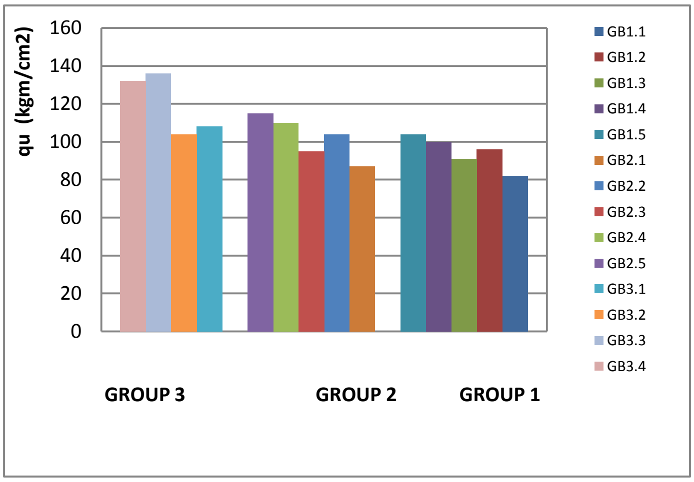

Figure (11): Ultimate shear transfer for the tested specimens.

E. ***Load-Deflection Curves:***

The deflection of the tested steel I-beam and composite beams was measured at 0.25, 0.5 and 0.75 span and the maximum deflection plotted against the applied load from zero loading up to failure.

It can be noticed that the relation between the load and deflection was nearly linear up to cracking load then it was nonlinear due to excessive cracking in the concrete.

For group (1), Comparing the load-deflection curve of the composite beams and the steel I-beam, it can be noticed that the composite beams had a deflection less than the steel I-beam at the same load level. the composite beams GB1.1had a deflection less than the steel I-beam at the same load level with about 40%,the composite beams GB1.2 had a deflection less than the steel I-beam at the same load level with about 35%,the composite beams GB1.3 had a deflection less than the steel I-beam at the same load level with about 37%,the composite beams GB1.4 had a deflection less than the steel I-beam at the same load level with about 18%,the composite beams GB1.5 had a deflection less than the steel I-beam at the same load level with about 33%as shown in figure (12), Finally strengthening steel I beam with concrete flange lead to decrease deflection by about 18% to 40%

For group (2), Comparing the load-deflection curve of the composite beams and the steel I-beam, it can be noticed that the composite beams had a deflection less than the steel I-beam at the same load level. the composite beams GB2.1 had a deflection less than the steel I-beam at the same load level with about 35%, the composite beams GB2.2 had a deflection less than the steel I-beam at the same load level with about 30%, the composite beams GB2.3 had a deflection less than the steel I-beam at the same load level with about 27%, the composite beams GB2.4 had a deflection less than the steel I-beam at the same load level with about 15%, the composite beams GB2.5 had a deflection less than the steel I-beam at the same load level with about 27%, Finally strengthening steel I beam with concrete flange lead to decrease deflection by about 18% to

40%, Finally strengthening steel I beam with concrete flange lead to decrease deflection by about 15% to 35%.

For group (3), Comparing the load-deflection curve of the composite beams and the steel I-beam, it can be noticed that the composite beams had a deflection less than the steel I-beam at the same load level. the composite beams GB3.1 had a deflection less than the steel I-beam at the same load level with about 28%, the composite beams GB3.2 had a deflection less than the steel I-beam at the same load level with about 10%, the composite beams GB3.3 had a deflection less than the steel I-beam at the same load level with about 7%, the composite beams GB3.4 had a deflection less than the steel I-beam at the same load level with about 18%, Finally strengthening steel I beam with concrete flange lead to decrease deflection by about 7% to 28%.

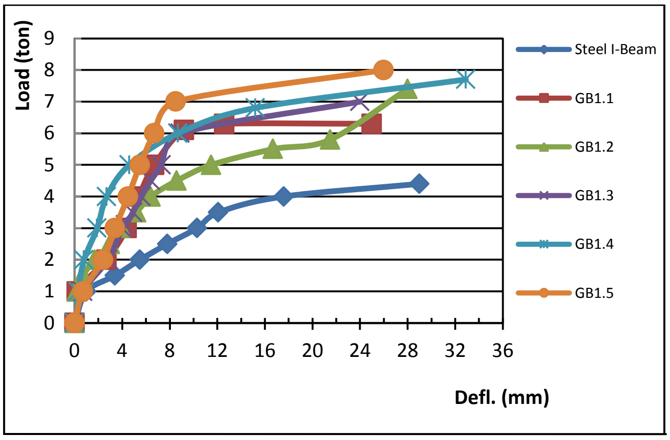

Figure (12): Load Deflection Curves at mid span (group 1)

- Figure (13) illustrate the deflection pattern along the span of the tested specimens at ultimate loads. From the figure, it can be noticed that the steel I-beam had higher deflection than the composite beams at the ultimate load.

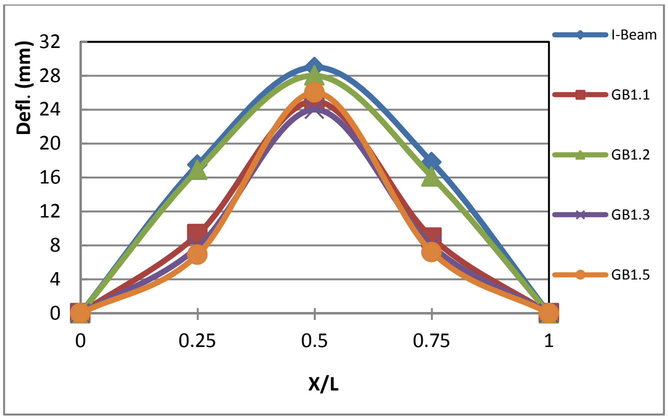

Figure (13): Vertical Deflection Pattern at ultimate load (group 1)

VI. Conclusions:

- The Ultimate load of tested steel I-beam increases about (43% to 52%) as the strengthening slab thickness increase in case of top flange is at the bottom of slab thickness.
- The Ultimate load of tested steel I-beam increases about (59% to 82%) as the strengthening slab thickness increase in case of top flange is at the mid of slab thickness.
- The Ultimate load of tested steel I-beam increases about (68% to 88%) as the strengthening slab thickness increase in case of top flange is at the top of slab thickness.
- The Ultimate load of tested steel I-beam increases about (75% to 238%) as the strengthening slab width increase from 30 cm to 50 cm.
- The vertical deflection of tested steel I-beam decreases as the strengthening slab thickness increase.
- Strengthening of steel I-beam with a reinforced concrete slab led to a decrease in vertical deflection.
- The shear strength of tested steel I-beams increases as the slab thickness increase. The shear strength of tested steel I-beam GB1.3 with 8 cm slab thickness about 88% of the tested steel I- beam GB3.2 with 12 cm slab thickness.
- The shear strength of tested steel I-beams increases as the slab width increase. The shear strength of tested steel I-beam GB3.2with 12 cm slab thickness and 30 cm slab width was about 76% of the tested steel I- beam GB3.3 with 12 cm slab thickness and 50 cm slab width.

References

[1] American Concrete Institute Building Code Requirements for Structural Concrete and Commentary. ACI 318-63, 1963.

[2] E.C.P. "Egyptian Code of Practice for design and construction of reinforced concrete structures".

[3] ACI-ACSE committee 333, "Tentative recommendations for design for composite beams and girder for buildings" ACI, Dec.1960. PP.609-628.

[4] Ahmed Moussa, "Strengthening of reinforced concrete beams by adding new concrete ", M.sc. thesis. Faculty of Engineering. Ain Shams University 1988.

[5] Bryson, J.O., Skoda, L.F., & Watstein, D. Flexural Behavior of Prestressed Split-Beam Composite Concrete Sections. PCI Journal, 10(3), 77-91, 1965.

[6] Ihab A.H., "Effect of shear connectors on composite concrete beams" M.sc. thesis, Faculty of Engineering, Cairo University 1991

[7] Tan k. H., Gruan L. W., Lu. X and lim T. Y., "Horizontal shear strength of indirectly loaded composite concrete beams" ACI structural journal, Vol. 96, No.4, july-august1999, pp.533-538.