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FLEXURAL TESTING OF VARIOUS COMPOSITE-BEAMSUNDER QUASI-STATIC LOADS

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Abstract

The successful interaction between concrete and steel has inspired researchers to develop composite structural systems. Steel and concrete are utilized in various configurations to reduce construction costs and assure optimal load-response behavior. Since the response spectrum of the composite system varies from one system to another, adequate understanding of the composite system behavior is essential to guarantee a desired response. Several parameters affect the flexural capacity and failure mode of a composite section, such as geometry, material properties and bond. In practice, advanced material mechanics and numerical modeling can be utilized for simulating section response, however, variability in the material response hinders accurate prediction. To serve as a benchmark and facilitate optimal composite section design, this paper presents a thorough experimental investigation of four types of composite beams under flexural loading. The first type represents reinforced concrete T-shaped beams confined by structural steel members. The second system comprises steel tubes filled with concrete. The third type consists of an open web steel joist encased in reinforced concrete. The fourth system represents rectangular shaped RC beams strengthened by steel plates. The results confirm the diversity of behavior of composite sections and reveal significant enhancement in the failure mode and flexural behavior as compared to control non-composite sections.

Keywords

Composite; In-filled hollow tubes; Encased steel joists; Retrofitting.

1. INTRODUCTION

Composite construction comprising structural steel and concrete is becoming widely popular due to the effective and successful interaction between the two materials. Steel mainly provides strength and ductility and can be efficiently utilized for retrofitting of existing structures, whereas concrete provides stiffness, workability and fire and corrosion resistance. Recently, both gravity and lateral-loading resisting systems in civil engineering structures are being executed as composite systems (Bai & Hueste, 2003)(Yan & Liew, 2016). Although the behavior of concrete and steel material has been well studied and understood, their composite action yield a more favorable, yet more complicated behavior that can be studied on case by case basis(Aslani, Uy, Tao, & Mashiri, 2015)(Chen, Chen, & Shen, 2018)(Yuan, Du, Shokouhian, Ye, & Schafer, 2019). For example, structural steel can be used to provide confinement for concrete which can significantly postpone plastic failure, on the other hand concrete can provide encasement for steel to avoid premature compression buckling.

Several numerical approaches and tools are being utilized to model concrete-steel behavior (Zona & Ranzi, 2011)(Nie, Tao, Cai, & Chen, 2011) (Slika & Saad, 2018), however experimental studies are often the benchmark for any suggested configuration. In practice, experimental testing of suggested steel-concrete designs serves as a reference for validation of numerical models and to uncover actual limitations and challenges. Therefore, this study presents an experimental investigation of the flexural behavior of four different composite beam systems. In preparing the experiments and designing the test beams, design provisions of ACI 318, AISC-LRFD Specification, and the AISC Seismic Provisions were adopted. A summary of each system is presented below.

The first composite system, or group (A), represents reinforced concrete (RC) T-shaped beams that simulate existing dropped beams in solid slabs. For the purpose of strengthening, longitudinal jacketing structural steel composed of angles and plates is selected. The steel sections are simply wrapped around the RC beam and tied together by batten transverse plates and shear studs. Thus, a confinement affect is produced by the steel jacket on the RC beam causing improved flexural behavior for the existing beam. This system is very attractive and efficient for upgrading of weak RC members (Elnashai, 1999). In group (A), four similar RC beams with T-cross-sections are designed and constructed. One beam is utilized as a control beam, while the remaining samples are confined by four steel angles and two steel plates using batten plates and shear studs at variable spacing.

The second composite system, or group (B), comprises steel tubes filled with plain or fiber reinforced concrete (FRC). This system is advantageous in the full tightening effect enforced by the steel tube on the concrete, whereas the filling concrete greatly postpones the local buckling of the steel tube. Consequently, the yield and compressive strengths of the tube and the filling concrete, respectively, can be attained leading to excellent flexural behavior. The use of FRC instead of plain concrete further enhances the structural integrity of the section under large deformations (HwanMin, 2018). Also, due to the significant post-cracking tensile strength of FRC, this system possesses improved shear strength, thereby permitting the beam to yield in a ductile flexural mode. This system eliminates the need for form-work and bar arrangement, tasks that conventionally absorb a great deal of time and labor. It can be used as precast joists for long spans with significant reduction in dead loads and deflections (Soundararajan & Shanmugasundaram, 2008). In group (B) four hollow-rectangular steel tubes have been selected, where one tube is used as a control specimen, and the other three tubes are filled with either plain concrete of FRC.

The third composite system, or group (C), consists of open-web steel joists encased either in plain or FRC. In such elements, the steel section provides majority of the strength and ductility, while reinforced concrete provides most of the stiffness besides being a fire-proofing layer for the steel section. The main objective of encasement of steel joists in concrete is to prevent buckling of the compression members under bending loads, thus enhancing the flexural resistance of the steel joist(Goel & Khuntia, 2000)(Khuntia & Goel, 1998). Minimal transversal reinforcement (stirrups) is used in the composite beam mainly to prevent concrete spilling under large deformations. Besides, no shear connectors between the steel joist and the surrounding concrete are required. Furthermore, the integrity of concrete especially under large deflections is enhanced by the use of steel fibers. This innovative system can be used for cast-in-place or precast construction, with less labor cost and construction time. In group (C), four specimens have been constructed. Two control specimens represent a bare steel truss joist and a rectangular RC beam, while the other two specimens represent encased truss joists.

The fourth composite system represents embedded RC beams in ribbed-slab floors with rectangular cross sections. Steel plates with variable lengths are used to strengthen these specimens. The strengthening scheme is in form of two steel plates at each of the bottom and top faces of each specimen. The steel plates at both faces are connected through the RC section by means of shear connectors. Various lengths of the steel plates were examined in this group. This composite system can be implemented as a retrofitting technique for weak RC beams or columns (Sasmal, et al., 2011). In group (D), five specimens have been constructed and tested. One specimen is used as a control one, while the other four specimens are strengthened by steel plates.

The main objective from this experimental study is to compare between the flexural behavior of the control specimen in each group and the composite specimens mainly to specify the degree of improvement regarding strength (load capacity) and ductility (deflection) and identify actual limitations of each composite system. All specimens are tested under two quasi-static loads near the mid-span section.

2. EXPERIMENTAL PROGRAM

2.1 Confined T-shaped RC Beams

2.1.1 Description of the specimens

Four T-shaped reinforced concrete beams are casted for this experiment. Each beam has a 1700 mm long length and web and flange and dimensions are 200mm x 100mm and 250mm x 50mm, respectively. The used concrete has an average 28-day compressive strength of 31.8MPa. Two 8 mm diameter - Grade 40/60 reinforcing bars, are used as bottom longitudinal reinforcements, while two 4 mm are used as a top reinforcement in each beam. The clear cover in each side is 15mm. Also, two 4 mm bars are used at the top-side of the beam. The transversal reinforcement is 6 mm diameter stirrups, Grade 24/35, at 200mm spacing. The average yield and ultimate strengths from tension tests are 440.9 MPa and 688.8 MPa for reinforcing bars, and 251.1 MPa and 368.3 MPa for stirrups. More details of this section are presented by the authors in (Hamad, Masri, Basha, & Baalbaki, 2011). This experiment is presented for completeness of the study and for comparing it with other retrofitting composite section.

To confine the three specimens, the following configuration is adopted: At the bottom corners, two equal-legs angles are placed, while at the stem-to-flange junctions two unequal-legs angles are placed near the bottom face. In addition, three welded batten plates are used in the transverse direction to tie the four angles around the stem of the RC beams. Also, two identical plates are placed at the upper side of the flange. The unequal-legs are connected to the plates by a two threaded studs through the flange at a specified spacing. Various battens' and studs' spacing are examined. A cross-section detailing for the confined beams is shown in figure 1 below.

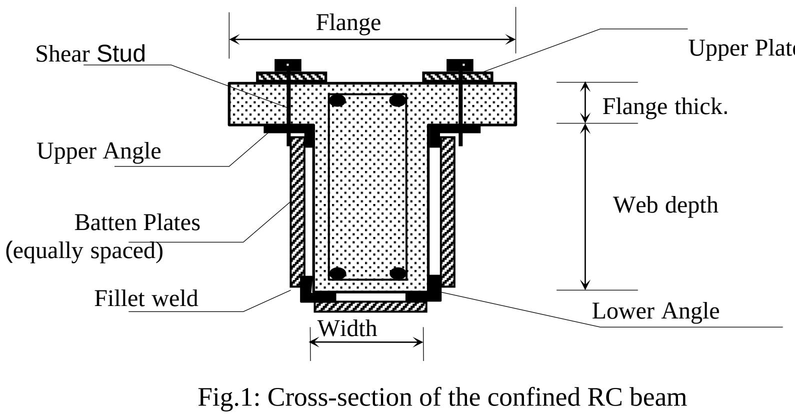

Fig.1: Cross-section of the confined RC beam

All structural steel elements have a high tensile strength in this experiment. For example, the average yield and ultimate strengths from tension tests are 364.4 MPa and 532.5 MPa, respectively. Mild steel is used for the shear studs with an average yield and ultimate strengths from tension tests of 255 MPa and 378.4 MPa, respectively. Details of the four specimens in group (A) are shown in table 1.

Table 1: Specimens' details in group (A)

Specimen	*Cross-Section* $b_f \times h \times t_w \times t_f$ *(mm)*	*4 Steel Angles* *a x b x L x t* *(mm)*	*2 Steel Plates* *b x L (mm)*	*Batten Plates* *b x t - spacing (mm)*	*Studs* *□□S(mm)*
TS 1-Control	250x 200x100x50	-----------------	----------------	-----------------	---------
TS 2	250x 200x100x50	2Ls 40x20x1500x3 2Ls 30x30x1500x3	60x1500x3	50x3 - 300	8 - 300
TS 3	250x 200x100x50	2Ls 40x20x1500x3 2Ls 30x30x1500x3	60x1500x3	50x3 - 250	8 - 250
TS 4	250x 200x100x50	2Ls 40x20x1500x3 2Ls 30x30x1500x3	60x1500x3	50x3 - 150	8 - 150

2.1.2 Experimental results

A two point loads 250 mm apart was used to test the specimens that are simply supported with a clear span of 1500 mm. Analytically, the load capacities of the RC beam and the confined beams are calculated to be 31.5 kN, and 78 kN - 85 kN - 112 kN for specimens TS2 – TS3 – TS4, respectively. Experimentally, the measured load capacities and the maximum deflections are 30.7 kN and 48 mm for the RC beam, and 81kN and 83 mm for specimen (TS2), 80 kN and 103 mm for specimen (TS3), and 101 kN and 107 mm for specimen (TS4), respectively. A clear plastic hinge is observed near mid-span upon failure of the specimens which indicated a flexural failure mode. Photos and load-deflection curves for group (A) specimens are shown in figure 2.

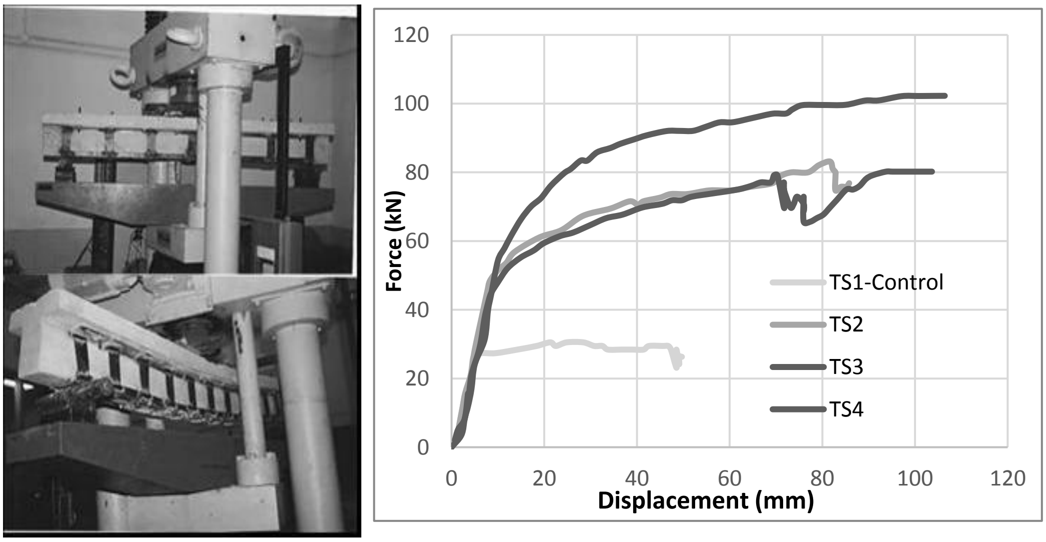

Fig.2: Photos and load-deflection curves for group (A) specimens

The yield load and the ultimate strength of the composite sample has increased significantly as compared to the RC sample. The yield load of the tested configuration is around twice that of the RC specimen and its ultimate strength has increased between 2.60 to 3.30 times that of the control RC specimen. Although, the elastic stiffness of the composite sample and the RC specimen are almost equal, the inelastic stiffness of the tested configuration witnessed a significant improvement as evident in the slower rate of the strength degradation. Another area of improvement is the ductility, where the tested samples attained a maximum deflection more than twice the value attained by the RC control samples. A summary of the elastic and ultimate deflections and ductility indexes is presented in table 2.

Table 2: Ductility indexes of group (A) specimens

Specimen	*□□y) mm*	*□□u)mm*	*□□y/□□u)*
TS1-Control	5	48	9.6
TS2	7	84	12.0
TS3	8	105	13.1
TS4	9	107	11.9

Results show that the behavior of the confined samples is governed by the spacing of shear studs and batten plates. For example, due to large spacing in specimens TS2 and TS3, the yield capacity of the steel angles and plates has not been reached allowing a premature shear failure in the studs due insufficient resistance. However, in specimen TS4, the decrease in spacing of the studs provided adequate shear flow resistance allowing the angles and plates to reach their yielding capacity. The failure mode in all specimens was flexural as the crack pattern propagated from mid-span and towards the supports.

The contribution of the composite components in the confined beams to the stiffness varies in the elastic and inelastic ranges. In the elastic range, the majority of the stiffness is provided by the RC beam section while the contribution of the steel angles is considered minimal in this stage. However, in the inelastic range after cracking of the RC beam, the stiffness is attained by the steel angles and plates. The curvature of the RC beam induced strain in the steel angles and resulted in a significant contribution to the stiffness by the provided structural steel. The steel angles and plates provided a confinement effect to the RC beam, thus delayed cracking besides increasing dramatically both the moment and shear resistance of the RC beam.

This retrofitting scheme can be practically implemented for dropped beams spanning between columns in solid slabs and bridges. Also, this scheme can be implemented easily and effectively for strengthening of weak RC beam-column connections with special detailing.

2.2 Concrete Filled Hollow Tubes

2.2.1 Description of the specimens

Four identical hollow- rectangular steel tubes (120mm x 50mm x 4mm) have been selected. The length of each tube is 1700 mm long. One tube is used as a control specimen, and the remaining three tubes are filled with plain concrete, steel fiber reinforced concrete, and glass fiber reinforced concrete. Mild structural steel is used for the tubes where the average yield and ultimate strengths from tension tests were 236.6 MPa and 358.2 MPa, respectively. The average 28-day compressive strength of concrete is 26.3MPa. Steel and glass fibers are used with a dosage rate of 0.25% by weight of concrete added directly to the concrete mixing system during the batching of the other ingredients. Details of the four specimens and schematic sketches in group (B) are shown in table 3 and figure 3, respectively.

Table 3: Details of the specimens in group (B)

Specimen	*Cross-Section h x b x t (mm)*	*Filling Material*
Hollow-Control	120x50x4	----------------
PC	120x50x4	Plain Concrete
FRC1	120x50x4	Plain Concrete + 0.25 % Steel Fibers
FRC2	120x50x4	Plain Concrete + 0.25% Glass Fibers

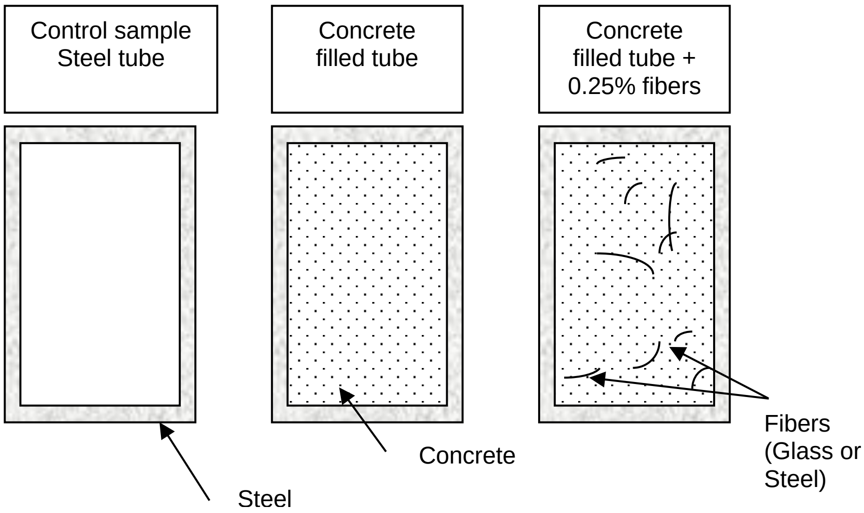

Fig. 3: Cross section for steel tube beams

2.2.2 Experimental results

A two point loads 250 mm apart was used to test the specimens that are simply supported with a clear span of 1500 mm. As evident in Figure 4 the measured load capacities and the maximum deflections are 38 kN and 60 mm for control Hollow specimen, and 62 kN and 80 mm for specimen PC in the top graph, 70kN and 100 mm for specimen FRC1 in the middle graph, and 68 kN and 105 mm for specimen FRC2 in the bottom graph, respectively. Photos and load-deflection curves of group (B) specimens are shown in Figure 4.

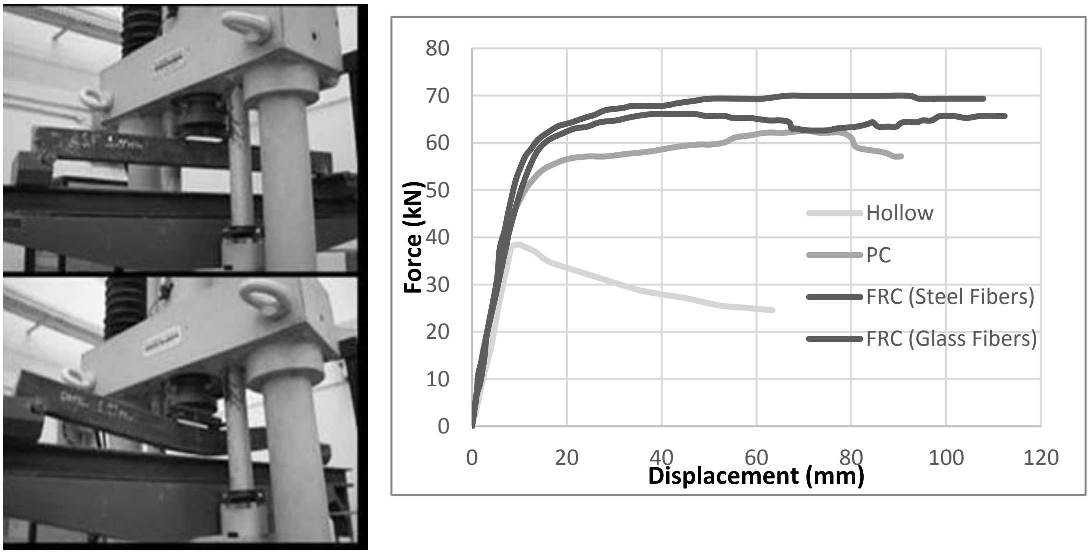

Fig.4: Photos and load-deflection curves for group (B) specimens

2.2.3 Discussion of Test Results

The flexural behavior of the filled steel tubes showed much improvement in comparison to the hollow steel tube. The tube has provided a full tightening confinement for the filler material; whereas the filler concrete has enhanced the compactness of the steel tube thus increasing its moment capacity by postponing the local deformations in the tube. The tensile strength of the tube and the compressive strength of the concrete are both attained. The ultimate strength of the filled tubes ranged between 1.63 to 1.84 times that of the hollow tube. The results are encouraging where the structural steel and the filler concrete interact efficiently to provide much better strength and ductility. As predicted, the elastic stiffness of all specimens are almost equal, while the inelastic stiffness of the filled specimens is much better than that of the hollow tube. Comparison of load-deformation curves is shown in Figure 4. The maximum measured deflections in the concrete filled tubes are 1.6 times that of the hollow tube, thus higher ductility is attained. Values for the elastic deflections, ultimate deflections and ductility indexes are presented in Table 4.

This system is advantageous in the tightening effect for concrete provided by the steel tube, whereas the filling concrete greatly postpones the local buckling of the steel tube.

Consequently, the yield and compressive strengths of the tube and the filling concrete, respectively, can be attained leading to excellent flexural behavior. Also, this system eliminates the need for form-work and bar arrangement, tasks that conventionally absorb a great deal of time and labor, and is characterized by an excellent cost performance.

Table 4: Ductility Indexes of Group (B) Specimens

Specimen	(Δ_y) mm	(Δ_u)mm	(Δ_y/Δ_u)
Hollow-Control	9	65	7.2
PC	10	90	9.0
FRC1	10	107	10.7
FRC2	10	105	10.5

2.3 Encased Steel Joists

2.3.1 Description of the specimens

Three identical, 1700 mm long and 200 mm deep, steel joists have been fabricated. Two equal-legs angles and rectangular bars are used as top-bottom chords and diagonals, respectively. Two control specimens are used in this group representing a bare truss joist, specimen (BT), and a rectangular reinforced concrete beam, specimen (RCB). The other two specimens are truss joists encased either in lightly reinforced concrete, specimen (ET1), or in FRC using steel fibers, specimen (ET2). The second control specimen RCB, is designed such that the area of steel rebar is equivalent to area of steel in ET1.The average yield and ultimate strengths for the structural steel from tension tests are 263 MPa and 378.2 MPa, respectively. The average 28-day compressive strength of concrete is 30.7 MPa. The average yield and ultimate strengths for the reinforcing bars from tension tests are 436.2 MPa and 674.6 MPa for reinforcing bars. Steel and glass fibers are used with a dosage rate of 0.25% by weight of concrete added directly to the concrete mix during the batching of the other ingredients. Details of the four specimens in group (C) are shown in Table 5, and a schematic sketch of the encased cross section is presented in Figure 5.

Table 5: Details of group (C) specimens

Specimen	***Steel Truss***		***Section hxb (mm)***
	Top & Bottom	***Diagonals***	
BT-Control	2Ls 40x40x4	PLs 40x20x4	---------
RCB-Control	-------------	-----------	240x130
ET1	2Ls 40x40x4	PLs 40x20x4	240x130
ET2	2Ls 40x40x4	PLs 40x20x4	240x130+ 0.25% fibers

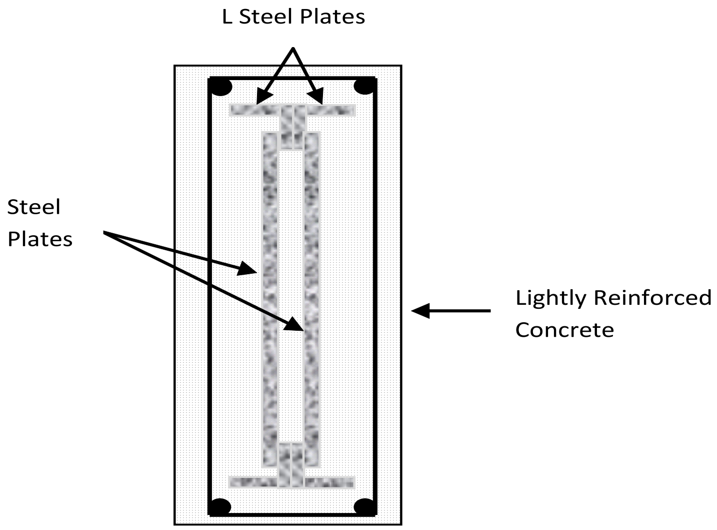

Fig.5: Cross-section of the encased truss joist (ET1)

2.3.2 Experimental results

As before, a two point loads 250 mm apart was used to test the specimens that are simply supported with a clear span of 1500 mm. The measured load capacities and the maximum deflections are 28.6 kN and 38 mm for specimen (BT), and 195 kN and 13.7 mm for specimen (RCB), 175kN and 38 mm for specimen (ET1), and 200 kN and 39 mm for specimen (ET2), respectively. Photos of the specimens and the load-deflection curves are shown in Figure 6.

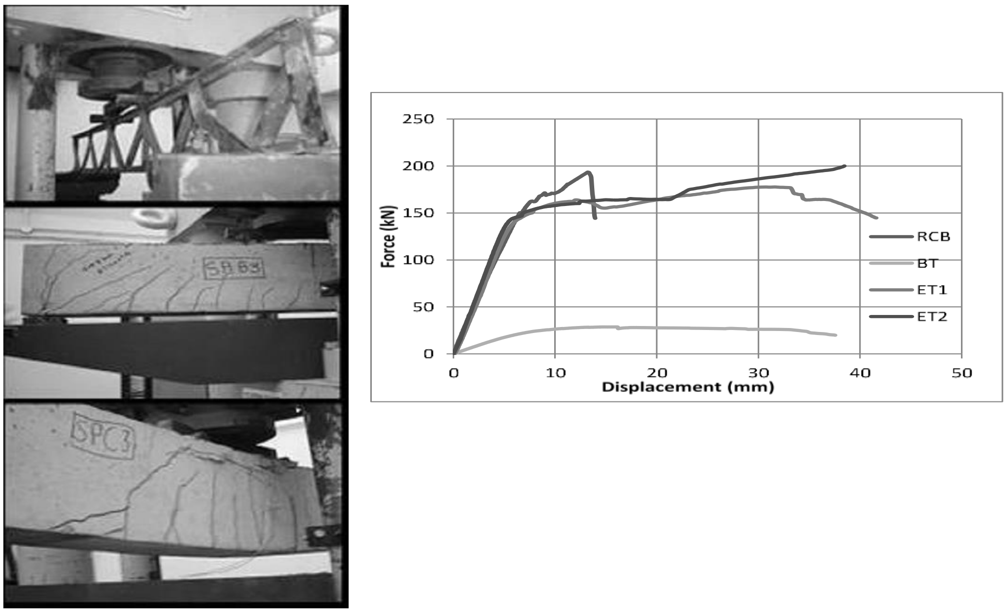

Fig.6: Photos and load-deflection curves of group (C) specimens

2.3.3 Discussion of Test Results

The test results of the encased beams reveal a great enhancement in the flexural behavior, where the strength of the encased steel joist in composite beams was much better that the bare steel joist. The increase in strength varied between 6.1 and 7 as compare to the value of the bare steel joist. The elastic stiffness of the composite beam was higher than that of the bare steel joist or the control RC beam by an average value of 6.

Regarding ductility, the behavior of the composite beams was more ductile than that of the bare steel joist. On the other hand, the strength of the RC specimen was higher than those of composite beams having equivalent reinforcement ratios mainly due to the difference between the yield and ultimate strengths of the reinforcing bars and the structural steel. The yield strength of the rebars was approximate 60 % more than that of the structural steel angles. However, the ductility of the composite beams was must better than that of the RC beam. The maximum measured deflection in the encased steel joists is 3 times that of the RC beam, and almost equal to that of the bare steel truss (BT). Values for the elastic deflections, ultimate deflections and ductility indexes are presented in Table 6.

The bare steel joist did not exhibit a resistance to bending in comparison with the other three specimens. This specimen failed prematurely due to buckling of web members and stress concentration at the location of welding between the diagonal plates and the angles bars. The ultimate capacity of specimens (ET1) and (ET2) were larger compared with that of specimen (BT). This is related to prevention of buckling in compression members due to full confinement by reinforced concrete. Thus, encasement of the steel truss in reinforced concrete increases its strength, stiffness, energy absorption, and prevents local buckling in compression truss members.

The use of conventional reinforcing steel is minimized in this system where the labor cost and construction time are reduced. It can be used in both cast-in-place or precast construction.

Table 6: Ductility indexes of group(C) specimens

Specimen	(Δ_y) mm	(Δ_u)mm	(Δ_y/Δ_u)
BT-Control	8	38	4.7
RCB-Control	7	14	2.0
ET1	8	41	5.1
ET2	8	39	4.9

2.4 Jacketed RC Rectangular RC Beams

2.4.1 Description of the specimens

Five reinforced concrete specimens having rectangular cross sections simulating wide embedded beams that span between the columns in ribbed slabs of RC buildings are tested in this series. Steel plates are used to strengthen four of these specimens, whereas, one specimen is used as a control specimen. The strengthening scheme is in the form of two steel plates at each of the bottom and top faces of each specimen. The use of two plates at each face instead of one plate is intentional for the sake of ease and fast installation of the plates, minimal damage to the existing partitions that are usually supported by the beams, and less disturbance to the occupants of the building. The steel plates at both faces are connected through the RC section by means of shear connectors. Various lengths of the steel plates were examined in this series to examine the effect of this length on the strength and behavior of the composite beam. Table 7 shows details of the jacketed rectangular RC specimens, and Figure 7 presents a schematic sketch of the cross section of a jacketed beam.

Table 7: Details of group (D) specimens

Specimen	Cross-Section h x b (mm)	4 Steel PLs t x b x L (mm)
SP (1)-Control	120x340	----------
SP (2)	120x340	4-3*120*900
SP (3)	120x340	4-3*120*1200
SP (4)	120x340	4-3*120*1500
SP (5)	120x340	4-3*120*1800

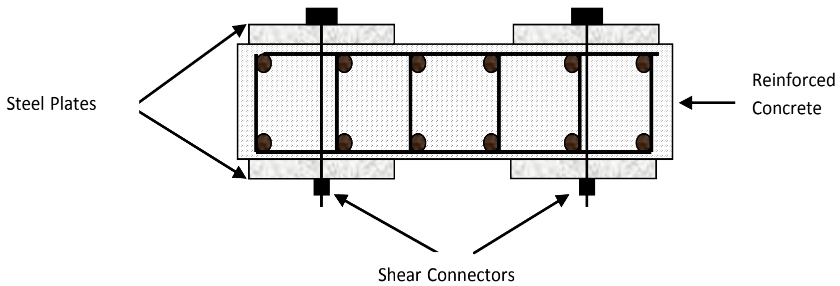

Fig.7: Cross-section of the jacketed RC beam.

The average 28-day compressive strength of concrete is 29.5MPa. Three 16mm diameter Grade 40/60 reinforcing bars are used for longitudinal steel. The stirrups are made from6mm diameter, Grade 24/35 bars. The average yield and ultimate strengths from tension tests are 440.7 MPa and 689.4 MPa for reinforcing bars, and 251.5 MPa and 371.8 MPa for stirrups. St52 structural steel is used for the strengthening plates. The average yield and ultimate strengths from tension tests are 368.2 MPa and 535.3MPa, respectively. High strength anchor bolts are used.

2.4.2 Experimental Results

A two point loads 300 mm apart was used to test the specimens that are simply supported with a clear span of 1800 mm. The load capacity and the maximum measured deflection of the control RC specimen (SP1) are 55 kN and 50 mm, respectively. However, the corresponding measured values in the four jacketed specimens (SP2-SP5) ranged between 67 kN and110 kN as a load capacity, and 55 mm and 125 mm as a deflection. Accordingly, the load capacity of the RC specimen is increased two times with a dramatic improvement in its ductility. Photos and load-deflection curves of group (D) specimens are shown in Figure 8.

2.4.3 Discussion of Test Results

Based on the crack patterns observed from the tested specimens, the failure modes of this type of composite beam is the “flexural failure mode” which closely resembles the flexural failure of an ordinary RC beam. Flexural cracks initiated at mid span and propagated gradually towards the ends of the steel plates. This phenomenon was observed in all specimens. At high deflections, consecutive fracture in the shear connectors started at the end connectors towards the middle ones. Each time a shear connector fractured, the strength of the strengthened beam dropped.

The test results for this series reveal significant enhancement in the flexural behavior of the control RC specimen. The results show that the effect of the steel plate length and the spacing of the shear connectors play the significant role in the behavior. The strength of the jacketed beams ranged between 1.25-2 times that of the control beam. The elastic stiffness of the jacketed beams is almost equal to that of the RC beam, whereas the inelastic stiffness is much greater than that of the RC beam. The ductility of the strengthened beams was more than three times that of the RC beam. Gradual strength degradation is observed in specimen 5 due to the fracture of the shear connectors, which were designed to transfer the yield capacity of the steel plates.

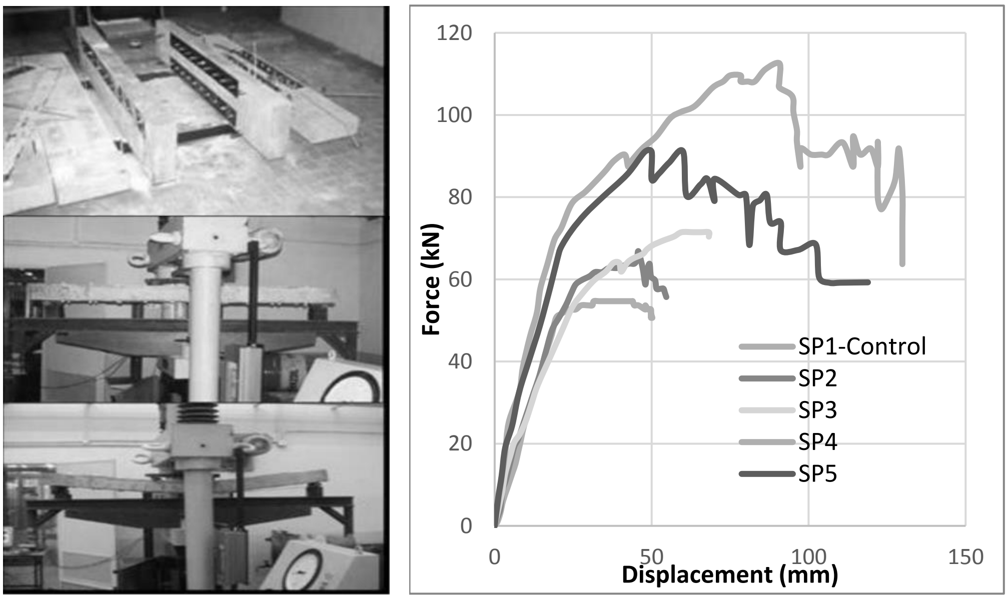

Fig.8: Photos and load-deflection curves of group (D) specimens

The maximum measured deflections in the jacketed specimens ranged between 1.0 and 2.4 times that of the control RC specimen. The ductility indexes of specimens SP4 and SP5 are the highest. Values for the elastic and ultimate deflections, and ductility indexes are presented in Table 8. This scheme can be practically implemented for strengthening of RC embedded wide beams spanning between two columns without removing the horde partition walls above and beneath the beam.

Table 8: Ductility indexes of group (D) specimens

Specimen	*□□y) mm*	*□□u)mm*	*□□y/□□u)*
SP1	20	50	2.5
SP2	22	55	2.5
SP3	25	70	2.8
SP4	22	125	5.7
SP5	21	120	5.7

3. RESULTS SUMMARY AND DISCUSSION

A summary of the four experimental programs is presented in table 9. The table lists the main applications of each composite beam type, advantages and practical limitations. In addition, the steel to concrete ratio was estimated for highest strength beam in each group.

Table 9: Summary of characteristics of the four experiments

Experimental Group	Main Uses	Advantages	Limitations	Steel to Concrete ratio (For Best case)
Group A	Retrofitting of drop beams (T-shape)	-Rehabilitating/Strengthening existing beams -Increases strength by 3.3 times compared to control beam -Increases ductility by 23%	-Requires experienced workmanship -Steel is prone to fire and corrosion	9.5%
Group B	Rectangular filled tubes: Precast or cast in place high strength beams/frames, long spans composite girders	-Prefabricated or cast in place -Increases strength by 1.63 times compared to control beam -Increases ductility by 25% -Doesn't require a formwork -Easy to cast	-Steel is prone to fire and corrosion	27%
Group C	Rectangular encased joist: Precast or cast in place high strength beams, long spans main girders	-Prefabricated or cast in place -Increases strength by 6.1 times compared to control beam -Increased ductility by 8.5% as compared to steel joist alone and 255% as compared to RC with same steel area -Avoid premature of steel due to local buckling -Provide steel protection from corrosion and fire	-Requires experienced workmanship	2.3%
Group D	Retrofitting of wide beams, accounts for existing partitioning walls	-Rehabilitating/Strengthening existing beams -Increases strength by 2 times compared to control beam -Increased ductility by 128% as compared to control beam -Doesn't require extensive work	-Steel is prone to fire and corrosion	3.3%

Therefore, as evident from table above, all composite systems improve both the strength and ductility as compared to non-composite or control specimens. Different applications, advantages and limitations can be identified in each system.

In the retrofitting composite systems, groups A and D, up to 9.5% and 3.3% steel by area of concrete are added to each group respectively. The added steel provided confinement to the RC beams and increases dramatically the moment and shear resistance of the tested beams by a factor of 3.3 and 2 in groups A and D respectively. The ductility is the major area of improvement for group D, where it is increased by 128%. The ductility of group A also increased significantly, by 23% as compared to control RC beams. On the other hand, minor drawbacks of these composite systems are identified, such as lack of concrete protection to fire and aggressive species. Another drawback of steel retrofitting is the requirement of more experienced labor as compared to the simpler FRP retrofitting, especially for beams in group A that possess a complicated spatial design.

The remaining two systems, groups B and C, can be used as precast or cast in place beams. In these systems concrete, with or without light reinforcement, is used to provide flexural stiffness and to delay or avoid steel local failure/buckling. The performance of the composite action yielded a better performance and a more desirable failure mode. When compared to steel alone control specimens, the composite system in both groups improved significantly the strength and the ductility of tested beams. The flexural capacity in Group C clearly confirms the advantages of composite system where it is increased by around 6 times that of bare steel joist. Group B's flexural capacity also improved significantly by a factor of 1.63 as compared to that of empty steel tubes.

Another favorable behavior of composite beams was recorded at the level of ductility as compared to steel-alone samples, where it is improved by 25% and 8.1% in groups B and C respectively. Limited drawbacks can be noted in each composite group configuration, for example group B is prone to corrosion and fire risks since steel is exposed, while Group C requires experienced workmanship, mainly to assemble the steel joist.

4. CONCLUSIONS

This study emphasizes the successful interaction between steel and concrete by comparing the flexural behavior of four different composite steel-concrete configurations to control non-composite systems. The flexural behavior of composite systems makes them an attractive alternative to traditional construction with different potential areas of improvement based on the adopted configuration, such as, strength, ductility, cost and providing a protective coating for embedded structural steel.

The main conclusions that can be emphasized from this study are the followings:

(1) The overall behavior of all composite beams is significantly better compared to the behavior of the control specimen in each group. The failure mode of composite beams is much favorable as compared to that of the concrete control specimens.

(2) Jacketing and retrofitting of RC beam sections by structural steel elements increases dramatically both the moment and shear resistance of the RC beam. The confinement effect provided by the steel jacket on the reinforced concrete beam has also improved ductility and resulted in better distribution of flexural cracks.

(3) The composite section behavior is critically dependent on the system configuration. Therefore, the presented wide range of composite systems configurations serves as a reference for practitioners and for numerical verifications of section behavior under quasi-static loads.

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