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Flexural Behavior of Concrete Composite Beams with New Steel Tube Section and Different Shear Connectors

Amer M. Ibrahim

Wissam D. Salman

Fahad M. Bahlol*

Department of Civil Engineering
College of Engineering
Diyala University
Diyala
Iraq

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A B S T R A C T

Hollow sections of steel are widely used in many engineering applications as structural members. This paper aims at studying the flexural behavior of a composite beams with steel tubes sections through a series of bending tests in order to study and examine the influence of the steel tube section shape, (square, rectangular and hexagonal) with the same shear connector type (headed stud or angle or perfobond) on its flexural behavior and the bending properties of these sections. As well as study the effect of different shear connectors types (headed stud, angle and perfobond) in the same steel tube sections (hexagonal, square, or rectangular) on the flexural behavior of the composite beams. The experimental program (in this work) has been divided into two groups, the first consists of nine specimens tests focusing on three types of steel section. Using shear stud first, angle at second, and perfobond at third as shear connector type. The second group consists of testing nine specimens of composite beams too. This group focuses on testing every steel section (hexagonal, square and rectangular) alone when using three types of shear connectors with it. All the specimens are of the same length, width and height (2000, 400 and 130) mm respectively. The tested steel tubes thickness was 2 mm, yield stress of 322 MPa and the ultimate strength was 390 MPa. The results showed that these shapes of hollow steel sections (hexagonal, square and rectangular) sustain the quality of services for the buildings, and these tested specimens are applicable by giving a distinctive strength and stiffness starting from 114 kN as ultimate load reaching to 170 kN. The experimental results proved that the perfobond and angle connector types are clearly effective shear connectors. Shear connector of the perfobond type increased the ultimate load of the composite beams by (6.25-9.74) % compared with the stud shear connector.

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تصرف الانثناء للعتبات الخرسانية المركبة بإستخدام مقاطع حديدية مجوفة جديدة و روابط القصية مختلفة.

عامر محمد إبراهيم — رئاسة جامعة ديالى، ديالى

وسام داوود سلمان — قسم الهندسة المدنية، جامعة ديالى

فهد محمد عبد الكريم — قسم الهندسة المدنية، جامعة ديالى

الخلاصة

تهدف هذه الدراسة الى تحري سلوك الانثناء للعتبات المركبة ذات المقطع الحديدي المجوف ذو أشكال مختلفة المقطع. يتركز البحث حول تحديد تأثير شكل المقطع الحديدي المجوف على تصرف العتبات المركبة الانشائي وذلك بأستخدام ثلاث اشكال للمقاطع الحديدية (السداسي ،المربع والمستطيل) مع ثبات نوع الرابط القصي المستخدم (رابط مسماري أو زاوية أو بيرفوبوند)، كذلك تحديد تأثير نوع الرابط القصي المستخدم (رابط مسماري، زاوية و بيرفوبوند) مع ثبات شكل المقطع الحديدي المجوف على السلوك الانشائي للعتبات المركبة. البرنامج العملي للدراسة تتضمن سلسلة من فحوصات الانثناء. تم إجراء فحص نقطتي تحميل لدراسة هذا التأثير لعتبات بسيطة الإسناد.البرنامج

العملي للدراسة يتضمن مجموعتين. الاولى تضمنت تسعة نماذج تركزت على فحص شكل المقطع الحديدي المجوف (سداسي أو مستطيل أو مربع) بتثبيت إستخدام رابط مسماري أولاً، زاوية ثانياً وبيرفوبوند ثالثاً كرابط قصي للعتبات المركبة. المجموعة الثانية تتضمن تسعة نماذج ايضاً ركزت على فحص كل شكل حديدي مجوف على حدة مع أختلاف نوع الرابط المستخدم (رابط مسماري، زاوية وبيرفوبوند). وجميع النماذج لها نفس المقدار من الطول و العرض وألارتفاع (2000، 400، 130) ملم. كما وأن سمك المقطع الحديدي المجوف هو (2) ملم و مقدار الاجهاد المرن (322) ميكاباسكال والاجهاد الأقصى (390) ميكاباسكال. أظهرت الفحوصات أن هذه المقاطع الحديدية لها قابلية للخدمات المختلفة في المنشآت وأنها قابلة للتطبيق إنشائياً من خلال إعطاء قوة وصلابة مميزة وصلت الى 114 كيلونيوتن كمقاومة قصوى الى 170 كيلونيوتن. النتائج العملية أثبتت أن (الزاوية والبرفوبوند) رابط قصية مؤثرة على العتبات المركبة بحيث أعطى البرفوبوند تحسن في التصرف الإنشائي وزيادة في التحمل الاقصى مقدارها (9,74-6,25) % أعلى من نماذج العتبات المركبة ذات الروابط القصية الثلاثة أنواع من المقاطع الحديدية المجوفة.

1. INTRODUCTION

Composite term means that more than one material are interferes to combine a distinctive unit mass offers several advantages over non-composite portion. In this case using the steel beam and the slab acting together as "Composite Beam" and their action is similar to the monolithic T-beam, concrete which is stronger (in compression) than (in tension). Moreover, steel is susceptible to buckling in compression (IS 11384-1985) [1]. The general advantages of these beams type are due to using an efficient connection between the two materials of reinforced concrete and structural steel while a headed stud was used in this study. There are several considerable advantages were achieved due to using of a composite action, which could be summarized as follows:

1. Efficient use of material.
2. Cost reduction.
3. Greater stiffness.
4. Extra usable space.
5. Saving in labor and other construction materials.
6. Sustainable effort.

This study aims to investigate the effect of the steel section shape on the structural behavior of the concrete composite beams and using three section shapes (rectangular, square and hexagonal). As well as studying the effect of shear connector type on the structural behavior on the concrete composite beams.

Many researchers presented scientific experimental and theoretical studies focusing on that behavior. Clause ES [2] concluded that the longitudinal bending stress across the width of the slab is not constant and the longitudinal stress tends to be maximum over the web of the steel section, and reduces (non-uniformly) away from the center-line of the beam. Johnson R., Molenstra N. [3] summarized a study on the use of partial shear connection in composite beams and showed that the slip capacity of the connectors should not be less than the maximum slip that required for the beam to reach its ultimate design load.

It was also shown that the maximum slip depended on many parameters, of which the degree of shear connection and span were the most significant.

Al-Darzi S. and Chen A. [4] considered the effect of using different types of shear connectors, by using headed stud, circular/regular perfobond, the experimental results showed that using a perfobond connector in composite beam enhanced the behavior of the beam which is represented by reducing deflection, slip and increasing the resistance.

Abdulmajeed KS [5] investigated the structural nonlinear behavior of simply supported composite steel-concrete beams. The study showed a good agreement between nonlinear three-dimensional finite element modeling and experimental results. Ten composite beams were reanalyzed using a nonlinear three dimensional finite element models with varied degrees of shear connection. Positive and negative bending moments acting on the beams are taken into account. Salman, W. D. [6] introduced an experimental and analytical study consisted of seven composite steel-concrete tube beams were tested to their ultimate strength. The researcher studied the structural behavior of the concrete composite beams by an applying external load to that simply supported composite beam in which concrete was connected together with steel circular tube by headed stud shear connectors. Those goals were demonstrated by specified variables, such as, thickness and diameter of the steel tube section. Ibrahim A.M. et al. [7] afforded a substantial study presenting the structural benefits that gained by using a composite beams that consisted concrete part and a circular steel tube as an alternative of the IPE steel beam. The behavior of the composite concrete structural steel tube beams with three types of shear connectors (Headed Stud, Angle and perfobond), is the main objective.

2. EXPERMENTAL WORK

This study consists of testing two groups of composite beams, each group has nine specimens of concrete composite beams with new steel tube sections instead of I-Section, details of the experimental specimens are tabulated in Table 1 and 2.

This study dealt with examining of the ultimate loads, central deflection, ductility, crack width and interface slip for all composite beams. The dimensions of the experimental specimens are (2000*400*130) mm, three of specimens are composite beams with hexagonal steel tube section, and length of six ribs is (57.74) mm as shown in Fig. 1. The difference between these nine specimens in first group is the type of steel tube section, the section shapes (hexagonal, square and rectangular). Where, three specimens of square steel tube section its dimensions are (100*100) mm as shown in Fig. 2, last three specimens are of rectangular steel section and its dimensions are (200*100) mm as shown in Fig. 3.

Thickness of steel tubes is (2) mm and all types of the steel sections have the same depth (100mm). First three specimens in first group have headed stud as a shear connector, second three specimens have angle as shear connector type, and final three specimens have perfobond as a shear connector. Second group has also nine specimens, every three of them are similar on the steel section type but different in shear connector type. Dimensions of the tube sections were different according to its shape but all they have sane depth (100) mm and interaction depth with concrete slab (20) mm.

The typical shape of the three steel tubes are shown as sections in three Fig's; length of all the steel tubes is (2000) mm. The headed shear stud connecters are used in order to prevent slip between the concrete slab and the steel tube and also to resist the longitudinal shear at the interface region between the steel tube and concrete slab, and to prevent the vertical separation between them, headed stud shear connectors of diameter (10) mm and overall length (75) mm with a head of diameter (19) mm and height (7) mm were welded using gas metal arc welding over top fiber of the steel tube in each specimen when used the shear studs as shown in Fig. 4.

Table 1

Details of Tested Specimens for First Group in This Study

Specimen	Type of Steel Section	Type of Shear Connector
CBHS	Hexagonal	
CBSS	Square	Stud
CBRS	Rectangular	
CBHA	Hexagonal	
CBSA	Square	Angle
CBRA	Rectangular	
CBHP	Hexagonal	
CBSP	Square	Perfobond
CBRP	Rectangular	

Table 2

Details of Tested Specimens for Second Group in This Study

Specimen	Type of Steel Section	Type of Shear Connector
CBHS		Stud
CBHA	Hexagonal	Angle
CBHP		Perfobond
CBSS		Stud
CBSA	Square	Angle
CBSP		Perfobond
CBRS		Stud
CBRA	Rectangular	Angle
CBRP		Perfobond

According to Johnson R.P, [8], total number of studs was (33) with spacing between them (60) mm according to the design requirements of the composite construction on Euro code 4, (2004) [6], angle of connectors details are show in Fig. 5, perfobond details and dimensions as display in Figs. 6 and 7 respectively. The shear connector's distribution shows in Fig. (8). Mechanical properties of the studs had been certified by the manufacturer as given in Table 3. The reinforced concrete slab consists of two layers of (4.75) mm @ (60) mm diameter of the deformed bars which were used in the two directions longitudinal and the transverse as shown in Fig. 10. A locally materials were used in producing a self compacted concrete as shown in Fig. 11, which include gravel, cement, sand, lime stone and water with super plasticizer as an admixture for concrete mixing. Natural gravel was used after washing and drying in air, then using a saturated surface of dry condition with (12.5)mm maximum size, gravel is complying with the requirements of the Iraqi standards I.Q.S No.5, (1984) [9] as shown in Table 6, as well as the grading which is tabulated in Table 7. Also by using an Ordinary Portland cement (Tasloja factory), a physical and chemical tests were conducted to ensure that the cement are comply with the requirements of the Iraqi standards I.Q.S No.5, (1984) [10].The chemical and physical tests results of cement are shown in Table 4. While natural silica sand was used which were provided from Aldooz region in Iraq as fine aggregate with maximum size of (4.75) mm, sand is comply with the requirements of the Iraqi standards Specification I.Q.S No.5, (1984) [11] as shown in Table (5). Lime stone material were provided from market and used, the ordinary tap water was used in mixing the concrete and curing for (28) days after casting, final equipment of material step was provided admixture that super plasticizer for the mixture. Several mixes were prepared to obtain the required compressive strength of concrete. A mix with weight percentage of (300 cement: 850 sand: 670 gravel: 235 lime stone: 200 water: 1.85 % S.P) were used with slump of (70) mm which was satisfied (EFNARC, 2002) [12]. The average concrete compressive strength of a standard cylinder ($fc'=30N/mm^2$) was determined using a standard compression tests. Simply supported composite beams specimens were tested after (28) days in Diyala university/engineering college / structural laboratory to get data Collection, under two concentrated loads that applied at the third points with (1900) mm clear span as shown in Fig. 9. They were prepared, cleaned and coated with a white color in order to reveal of possible cracks. After that, the load was applied and the readings were recorded for every (5) kN, and at each increment, manual measurements were recorded including the load, deflection, slip, crack width by data crack device. Table 8 presents the results of the tested specimens.

3. CONCLUSIONS PROGRAM

This paper described an experimental study that focused on the behavior and strength of the steel–concrete composite beams with different steel tube sections. The main conclusions that based on this study are:

- The suggested steel tube section shapes (hexagonal, square and rectangular) are applicable and gave a good strength and stiffness. And this means that these sections were proved sections and they could be in the execute civil engineering constructions.
- These shapes of the hollow steel sections (hexagonal, square and rectangular) sustain the quality of services for the buildings, for example, it could be used for extending the electrical connections inside the structures and transporting a soft materials like oil products and water.
- These specimens are applicable by giving a distinctive strength and stiffness starting with 114 kN for (CBHS) specimen as an ultimate load and reaching to 170 kN in (CBRP) specimen.
- The rectangular steel section gives more effective structural behavior on composite beams due to its effective steel area.
- Shear connector type perfobond gives a higher strength, (6.25% to 9.74%) which increase the ultimate load percentage more than stud shear connector and (3.66% to 9.00%) compare with the angle connectors.
- The results showed that the required loads for obtaining the beams slips with perfobond connectors are more than

that of the stud connector. The specimens with a headed stud slipped under (88% to 91%) more than the specimens with the perfobond connectors as well as the same specimens got slip under (86% to 90%) more than the specimens with angle connectors, so it was considers the best connector type, among all.

- The tests showed that the three types of the shear connectors could be considered as ductile connectors that have adequate deformation capacity to be comparable with the shear connection plastic behavior assumption in the considered structure.

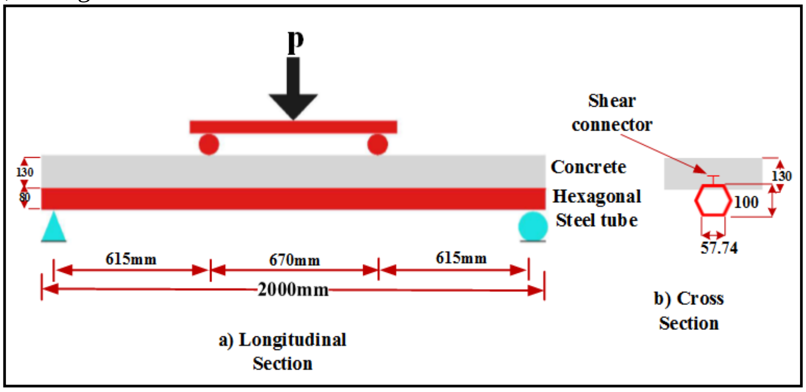


Fig. 1. Composite Beam with Hexagonal Steel Tube Section

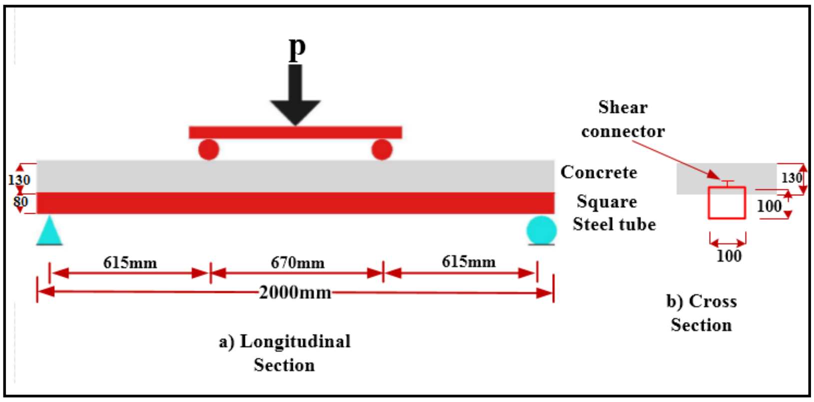


Fig. 2. Composite Beam with Square Steel Tube Section

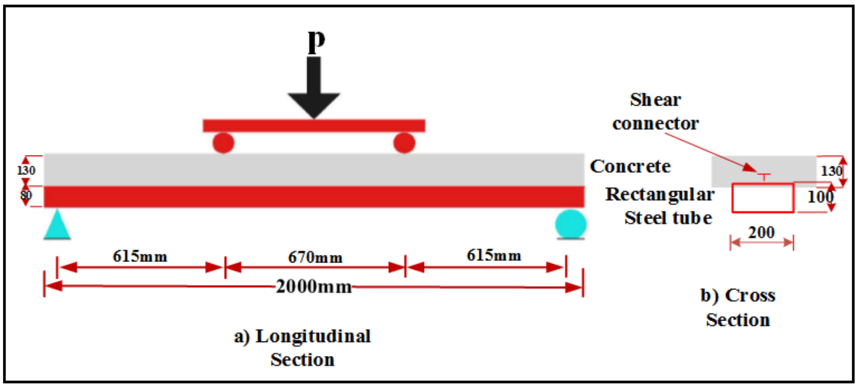


Fig. 3. Composite Beam with Rectangular Steel Tube Section

Fig. 4. Shear Stud Connector Details

Fig. 5. Angle Connector That Used in This Study

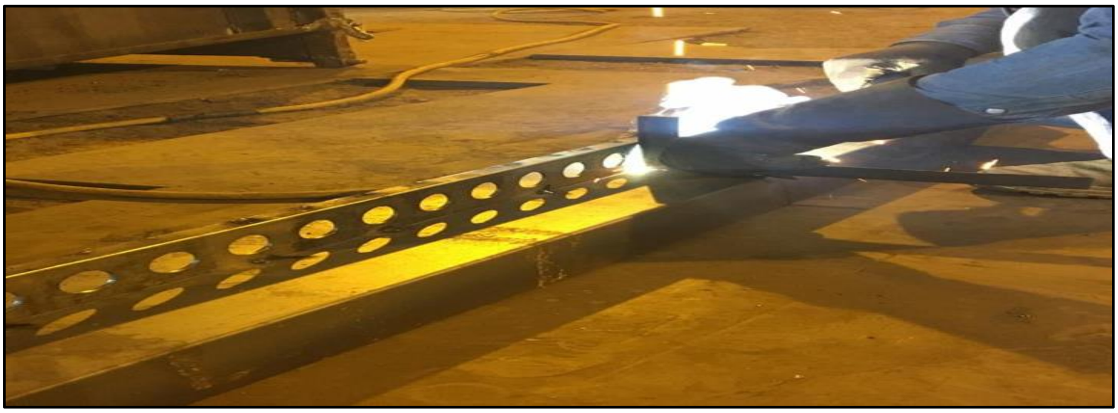


Fig. 6. Perfobond Connector That Used in This Study

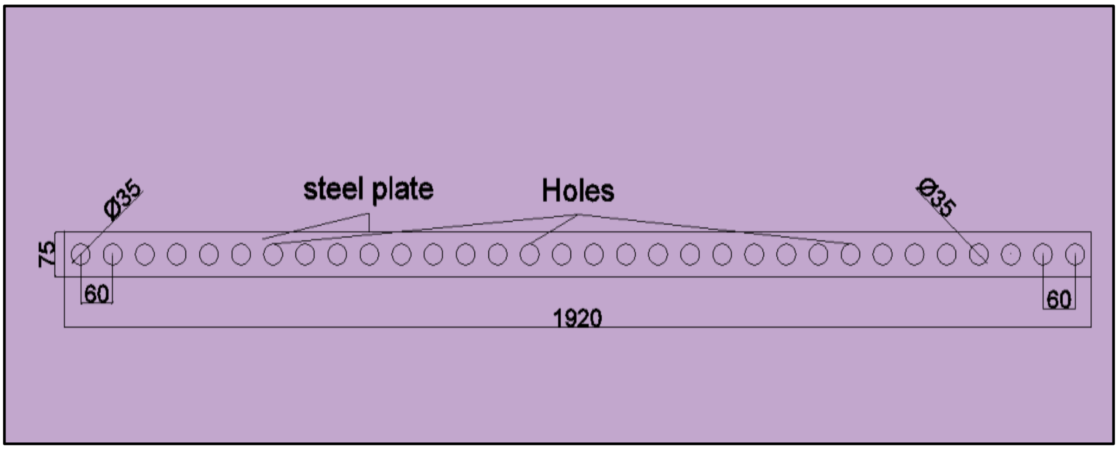


Fig. 7. Perfobond Connector Dimensions

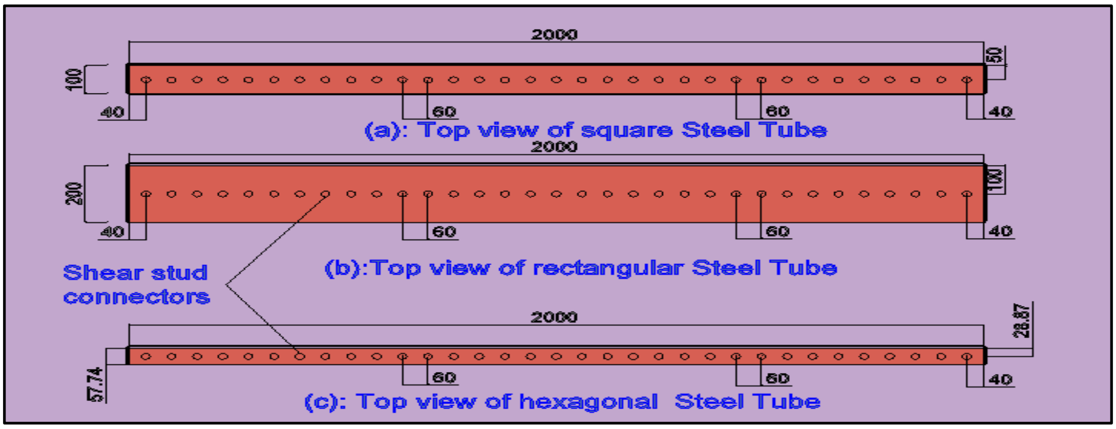


Fig. 8. Shear Connector Distribution on Three Steel Sections

Fig. 9. Testing Specimen by Two Points Loads Machine

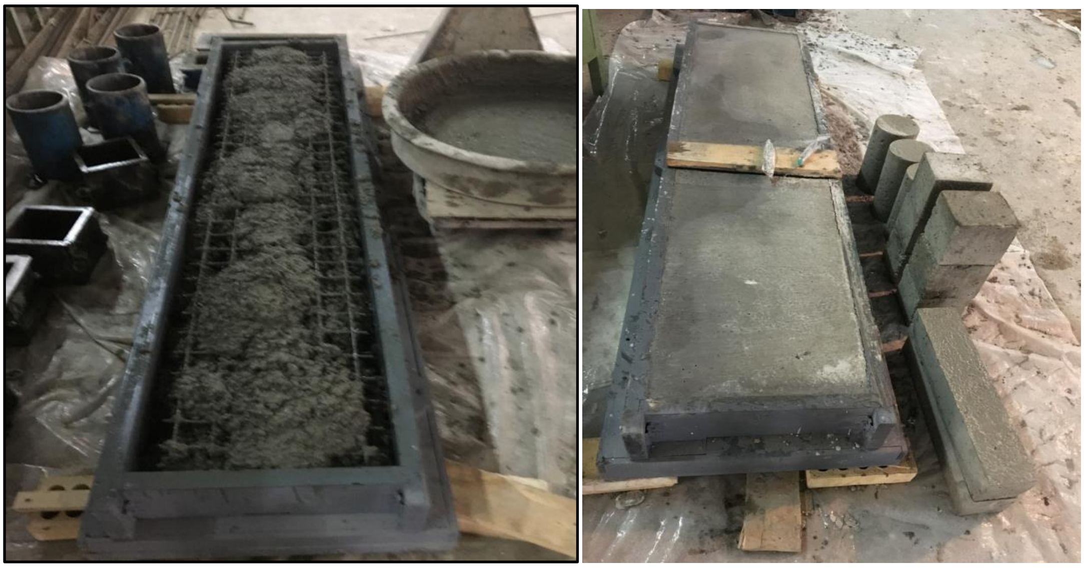
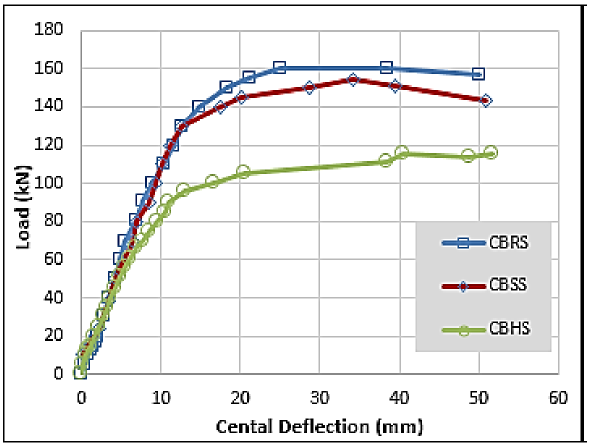
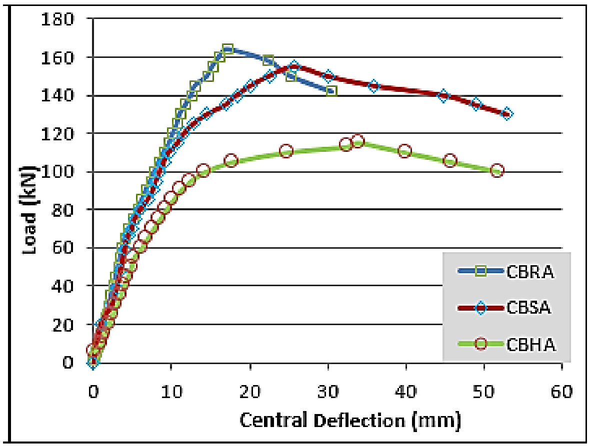


Fig. 10. Casting Specimen with Its Cubes, Cylinders and Prisms

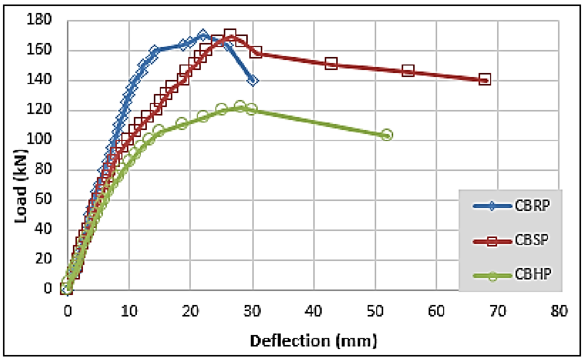
Fig. 11. Specimen under Loading Stages in the Test



(a)

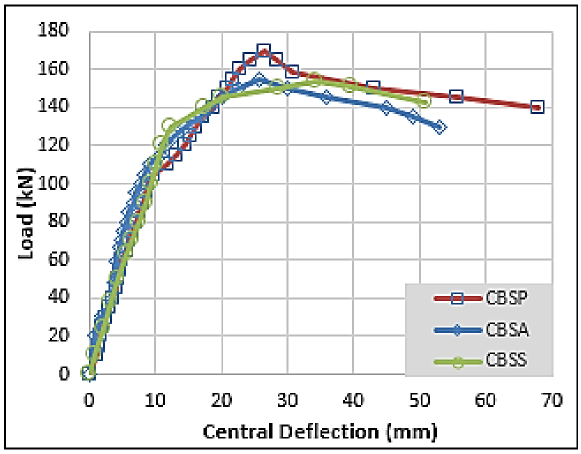


(b)

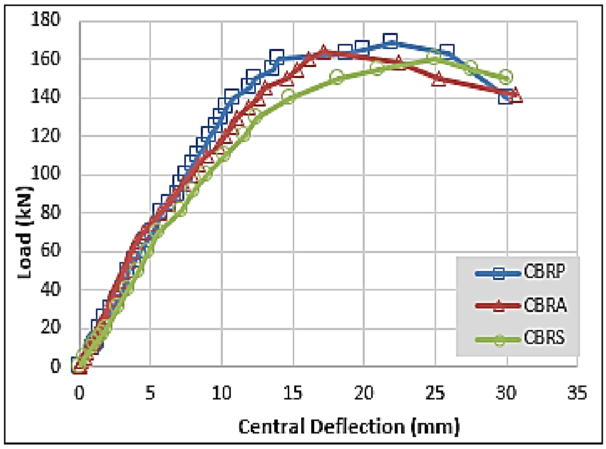


(c)

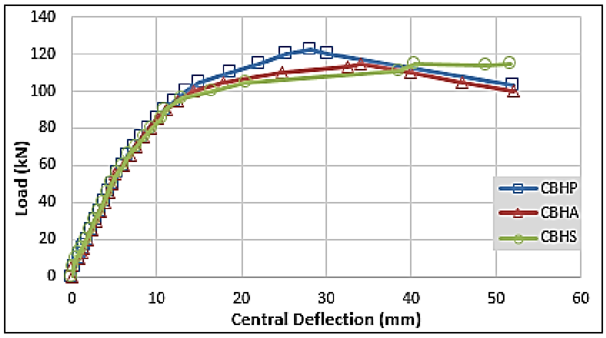
Fig. 12. Load – Central Deflection Curves for Group one, (a) Specimens with Stud Connectors, (b) Specimens with Angle Connectors, and (c) Specimens with Perfobond Connector



(a)



(b)



(c)

Fig. 13. Load – Central Deflection Curves for Group two, (a) Square Specimens, (b) Rectangular Specimens, and (c) Hexagonal Specimens

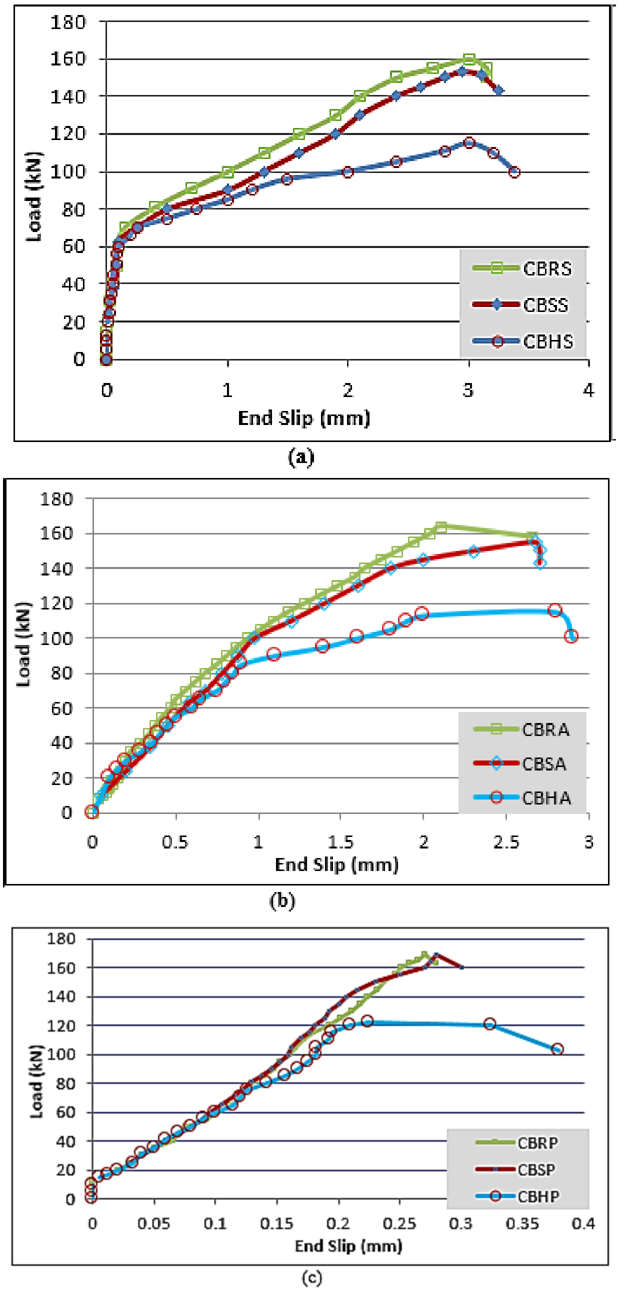


Fig. 14. Load – End Slip Relationship for Group one, (a) Specimens with Stud Connectors, (b) Specimens with Angle Connectors, and (c) Specimens with Perfobond Connector

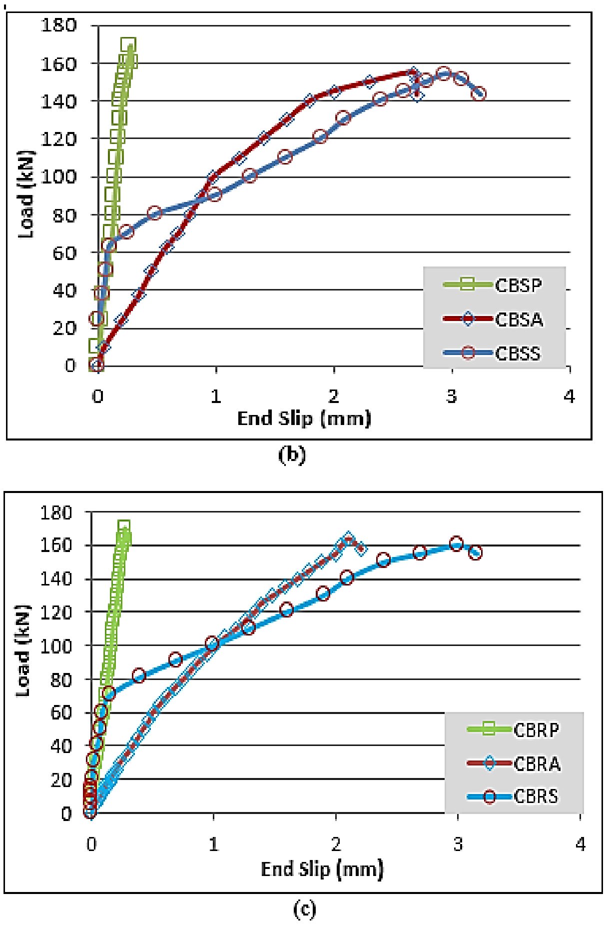
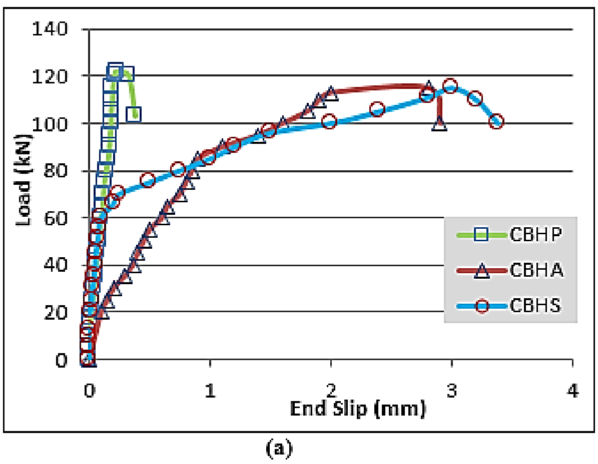
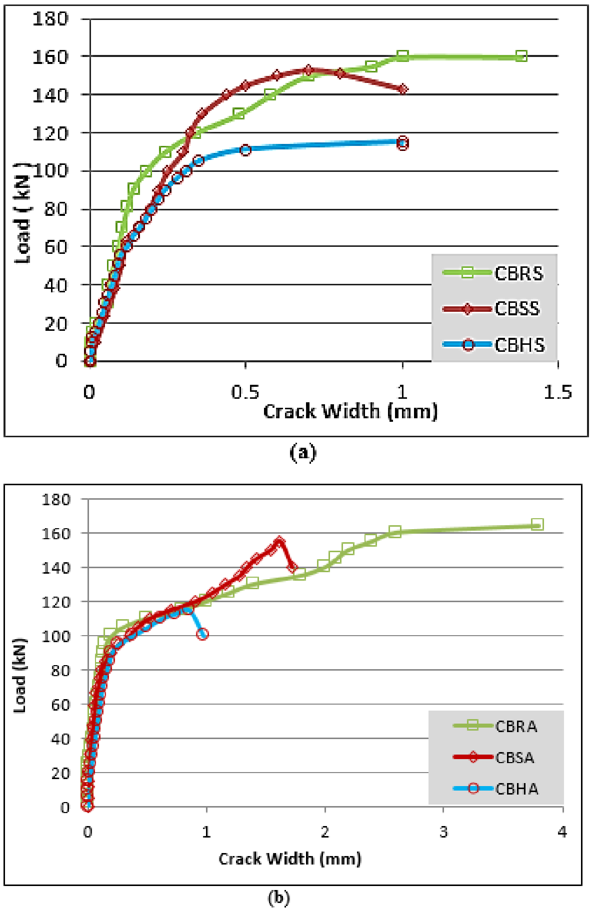
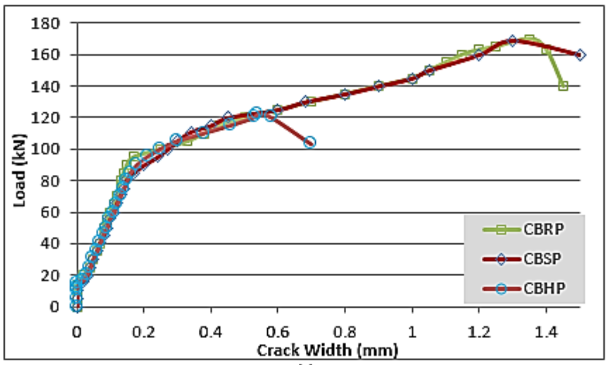


Fig. 15. Load – End Slip Relationship for Group two, (a) Hexagonal Steel Tube, (b) Square Steel Tube, and (c) Rectangular Steel Tube

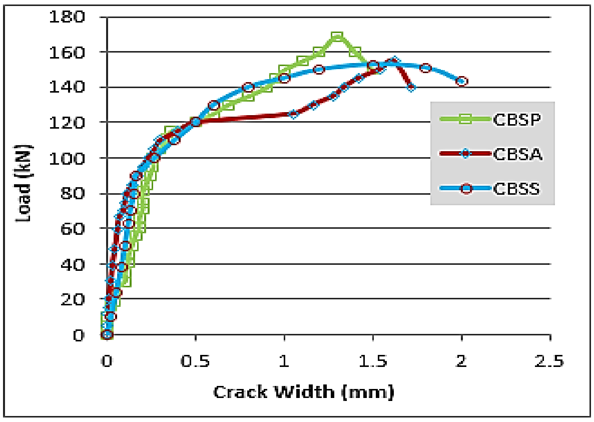




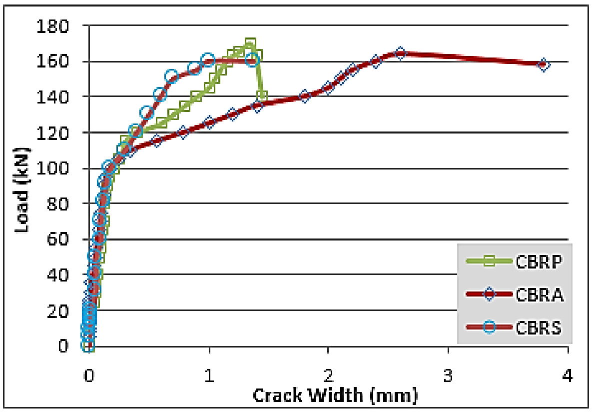


(c)

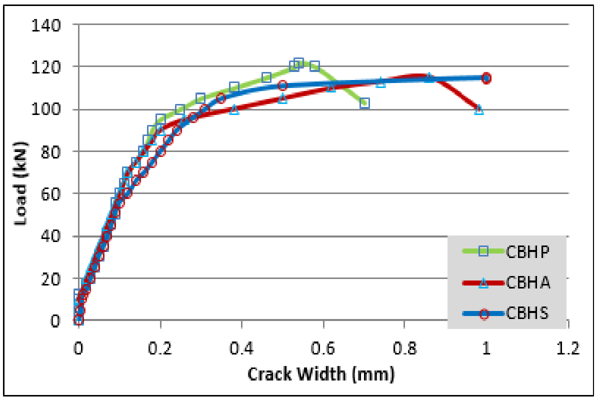
Fig. 16. Load – Crack Width Relationship for Group One, (a) Specimens with Stud Connectors, (b) Specimens with Angle Connectors, (c) Specimens with Perfobond Connector



(a)



(b)



(c)

Fig. 17. Load – Crack Width Relationship for Group Two, (a) Square Steel Tube, (b) Rectangular Steel Tube, and (c) Hexagonal Steel Tube

Table 3

Material Properties of Head Stud Connector

Strength Yield MPa	Tensile Strength MPa	Max. Elongation %
350	450	15

Table 4

Physical Properties	Test Results*	Limits of Iraqi Specification No.5/1984
Specific Surface Area (Blaine Method),cm^2/g	298.5	Not less than 230
Initial Setting, (min)	166	Not less than 45
final setting, (min)	255	Not greater than 600 min
Compressive strength, MPa at 3 days	18.76	$\geq$ 15.00
Compressive strength, MPa at 7 days	26.81	$\geq$ 21.00
Soundness(autoclave Method), %	0.35	$\leq$ 0.8

*The test was carried out in the laboratory of the Consulting Engineering Bureau/ Baghdad University.

Physical Properties of Cement

Table 5

Physical Properties of Fine Aggregate

Physical properties	Test Result*	Limits of (IQS No.45:1985)
Specific gravity	2.60	-
Sulfate content	0.11%	0.5% (max)
Absorption	0.75%	-
Clay content	2.3	5% (max)

*The test has been carried out in the laboratory of the Consulting Engineering Bureau / Baghdad University.

Table 6

Physical Properties of Coarse Aggregate

Physical properties	Test result*	Limits of (IQS No.45:1985)
Specific gravity	2.60	-
Sulfate content	0.08%	0.1% (max)
Absorption	0.70%	-
Clay content	0.4	3% (max)

*The test has been carried out in the laboratory of the Consulting Engineering Bureau / Baghdad University.

Table 7

Grading of Coarse Aggregate

Sieve size (mm)	%Passing by weight*	Limits of (IQS No.45:1985)
19	100	100
12.5	100	90-100
9.5	65.7	50-85
4.75	2.23	0-10

*The test has been carried out in the laboratory of the Consulting Engineering Bureau / Baghdad University

Table 8

Tests Results

Group	Specimen	Pu (kN)	$\Delta_{\text{at } 0.75Pu}$ (mm)	Ductility	Slip (mm)	Crack Width at 0.7Pu (mm)
G1	CBHS	114	10.18	1.20	3.38	0.2
	CBSS	154	7	1.31	3.25	0.19
	CBRS	160	7	1.14	3.15	0.16
	CBHA	115	10.15	1.23	2.9	0.16
	CBSA	155	6	1.33	2.67	0.11
	CBRA	164	6	1.22	2.1	0.11
	CBHP	122	11.03	1.36	0.38	0.16
	CBSP	169	8	1.38	0.28	0.16
	CBRP	170	7	1.14	0.28	0.14
G2	CBHS	114	10.18	1.20	3.38	0.2
	CBHA	115	10.15	1.23	2.9	0.16
	CBHP	122	11.03	1.36	0.38	0.16
	CBSS	154	7	1.31	3.25	0.19
	CBSA	155	6	1.33	2.67	0.11
	CBSP	169	8	1.38	0.28	0.16
	CBRS	160	7	1.14	3.15	0.16
	CBRA	164	6	1.22	2.1	0.11
	CBRP	170	7	1.14	0.28	0.14

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