Time dependent behaviour of composite beams with partial interaction for different types of shear connectors

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Abstract

The structural behavior of composite steel concrete beams with long term deflection was investigated, taking in considerations several variables including degree of shear connectors 50%, 75%, 100%, and type of connectors including headed and hooked studs smooth or deformed. Five composite steel-concrete beams were tested each consist of steel section W12x35 and 300x100 concrete slabs. The composite beams were tested under uniformly distributed loads for different time interval up to 180 days. The results showed that the degree of interaction have significant influence on the long- term behavior of the composite steel concrete beam . When the degree of interaction decreased from 100% to 75% then to 50% the maximum long-term mid span deflection increased about 35.1% and 65.9% respectively at 180 days after loading. Also, the end slip increased about 67.5% and 112.4% respectively at 180 days after loading. The results showed that the type of the used shear connectors has slight influence on the long-term behavior of the composite steel concrete beams. For certain degree of interaction (75%)with using headed and hooked studs smooth or deformed the maximum long-term mid span deflection decreased about 7.1% and 11.7%at 180 days after loading, and the end slip decreased about 4.8% and 12.5% at 180 days after loading.

Key Words: Time dependent, composite, partial interaction , shear connectors

التصرف الانشائي للعتبات المركبة ذات الربط الجزئي لأنواع مختلفة من رباطات القص مع الزمن

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الخلاصة

تمت دراسة التصرف الانشائي للعتبات المركبة من الخرسانة والفولاذ تحت تاثير الزمن حيث تم اخذ عدة متغيرات بنظر الاعتبار وهي درجة الربط (50%، 75%، 100%)ونوع رباطات القص (رباطات ذات القبعة ، رباطات خطافية ملساء ومحززة) . تم اجراء الفحوص على خمسة عتبات مكونة من مقطع فولاذي من نوع (W12x35) ويعلوه مقطع خرساني بابعاد (300x100) ملم . تم اجراء الفحص للعتبات الاختبارية عن طريق تسليط حمل موزع بصورة منتظمة بفترات متباعدة لغاية (180 يوم) . بينت النتائج ان لدرجة الربط (بين المقطع الفولاذي والخرساني) في العتبات الخرسانية المركبة التاثير الاكبر على التصرف الانشائي الذي يعتمد على الزمن . عندما تقل درجة الربط من 100% الى 75% ثم الى 50 % فن الحد الاقصى للاود يزداد بنسبة 53,1% و 65,9% على التوالي بعد 180 يوم من التحميل .وايضا" فان اقصى الازاحة نسبية بين مقطعي الفولاذ والخرسانة تزداد بنسبة 67,5% و 112,4% على التوالي ولنفس زمن التحميل لمدة 180 يوم . بينت النتائج ايضا" ان نوع رباطات القص المستعمل في البحث له تاثير قليل نسبيا" على التصرف الانشائي للعتبات المركبة التي تعتمد على زمن التحميل . فلنسبة ربط محددة(75%) ونوع رباطات القص المستخدمة (ذات القبعة) ، خطافات ماساء ومحززة فان اقصى اود في منتصف العتبة يقل بنسبة 7,1% و 11,7% لنفس زمن التحميل 180 يوم وايضا" فان اقصى ازاحة نسبية تقل بنسبة 4.8% و 12,5% لنفس زمن التحميل 180 يوم .

1. Introduction

Composite materials consist of two or more constituent material whose properties have an ability to create a unique mechanical, material and physical response for a variety of applications. The most

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important and most frequently encountered combination of construction materials is that of steel and concrete composite construction[1]. The simplest form of composite structure is composite steel-concrete beam, which is commonly used in the construction[1,2].

1.1 Time Effects of Composite Structure

Steel-concrete composite are a popular and economical form of construction in both building and bridges. The time – dependent analysis of composite beams with partial shear interaction requires the global behavior oh the structural system to be considered, in deference to the case of full shear interaction where a cross-section time analysis can be performed without investigating the global behavior as presented by Gilbert[3], Bradford and Gilbert[4], and Ghali and Faver[5]. In the early 90s several researchers investigated the time-dependent behavior of composite beam with partial interaction, some of the first studies were published by Bradford and Gilbert[6] and by Tarantio and Dezi[7,2].

Dezi, et al.[8] simplified the complex numerical methods with a method known as the algebraic method . The algebraic method used for non- complex composite structures. However, for shear connectors , the authors used the pseudo-elastic analysis because headed stud shear connectors are known to behave in a complex manner. This study is made possible by defining a modified Young' Modulus for concrete. These methods are the effective modulus EM method, and the mean stress MS method. The creep effect is evaluated by means of a pseudo-elastic analysis using the EM method and is defined in Eq.(1) whilst the shrinkage effect is modified by creep and evaluated by means of a pseudo-elastic analysis using the MS method as defined in Eq.(2):

$$\bar{E}_e(t,t_0) = \frac{E_C}{1+\varphi(t,t_0)} \tag{1}$$

$$E_{C,MS}(t,t_s) = \frac{E_C}{1+0.5\varphi(t,t_s)} \tag{2}$$

Where

E_c - elastic modulus of the concrete

$\varphi(t,t_0)$ - creep coefficient

t - loading time

t_0 - final time

t_s - age of concrete at the beginning of shrinkage

According to Gilbert [3], the creep coefficient changes with time, Value of creep coefficient reduce the elastic modulus of concrete as shown in Eq. (3).

$$\bar{E}_e = \frac{E_c}{(1+\psi\varphi)} \tag{3}$$

Where;

φ - creep coefficient and

ψ - aging coefficient where the most appropriate value of (1/2)is used in the German design code, DIN 1045–1[9] to allow for time dependent induced stress.

The relationship of the elastic modulus of concrete with respect to time indicates that the elastic modulus of concrete is reduced with respect to time. It reduces significantly up to 400 days , and after that the reduction value is less significant, bearing in mind that both equations suggested by Dezi, et al.[8] and Gilbert[3] are similar[2].

1.2 The Method of Time – Dependent Analysis of Steel – Concrete Composite Beams Behaviour[3].

In the service load analysis of composite beam, it is usual to assume full connection so that no slip occurs between the steel and the concrete. This assumption is usually quite reasonable, since at service loads the amount of slip is generally negligible. Perfect bond between the steel and the concrete is therefore assumed in subsequent analysis[2].

1.2.1 Short – Term Analysis[2,3]

In the case of the composite cross – section shown in Fig. (1), the flexural rigidity of the steel section (or its moment of inertia) plays an important and significant role in the behavior of the cross – section. It is often most convenient to transform the concrete deck into an equivalent area of steel and to carry out an elastic analysis of the transformed steel cross – section, or the steel portions of the cross – section may be transformed into equivalent area of concrete.

$$\left.\begin{aligned} A &= b\,D_c + (n_{s1}-1)\,A_{s1} + n_{ss}\,A_{ss} \\ B &= \tfrac{1}{2}\,b\,D^2_c + (n_{s1}-1)\,A_{s1}d_{s1} + n_{ss}\,A_{ss}\,d_{ss} \\ I &= \tfrac{1}{3}\,b\,D^3_c + (n_{s1}-1)\,A_{s1}d^2_{s1} + n_{ss}\,(A_{ss}\,d_{ss} + I_{ss}) \end{aligned}\right\} \quad (4)$$

Consider the transformed section in Fig. (1a). the area **A** and the first and second moment of area of the transformed section about the top fiber **B** and **I**, respectively, are:

Where;
A_{ss} is the cross sectional area of the steel I – section
I_{ss} is the moment of inertia of the steel I–section about its own centroid, and;n_{s1} and n_{ss} = are the modular ratios for the steel reinforcement (E_{s1}/E_c) and the steel I – section (E_{ss}/E_c), respectively.

The initial strain can be determined as follows:

$$\varepsilon_i = \varepsilon_{oi} - y\kappa_i \quad (5)$$

$$\varepsilon_{oi} = \frac{BM_i + IN_i}{E_c(AI - B^2)} \quad (6)$$

$$\kappa_i = \frac{AM_i + BN_i}{E_c(AI - B^2)} \quad (7)$$

where:

N_i is the resultant axial force on the transform section ($N_i = N_s$) and
M_i is the resultant moment about the top of the section ($M_i = M_s - N_s d_{ns}$)

Concrete and steel stresses are readily obtained from the strain diagram using:

$$\sigma_i = E_c\,(\varepsilon_{oi} - y\kappa_i) \quad (8)$$

$$\sigma_{si} = E_s\,(\varepsilon_{oi} - y\kappa_i) \quad (9)$$

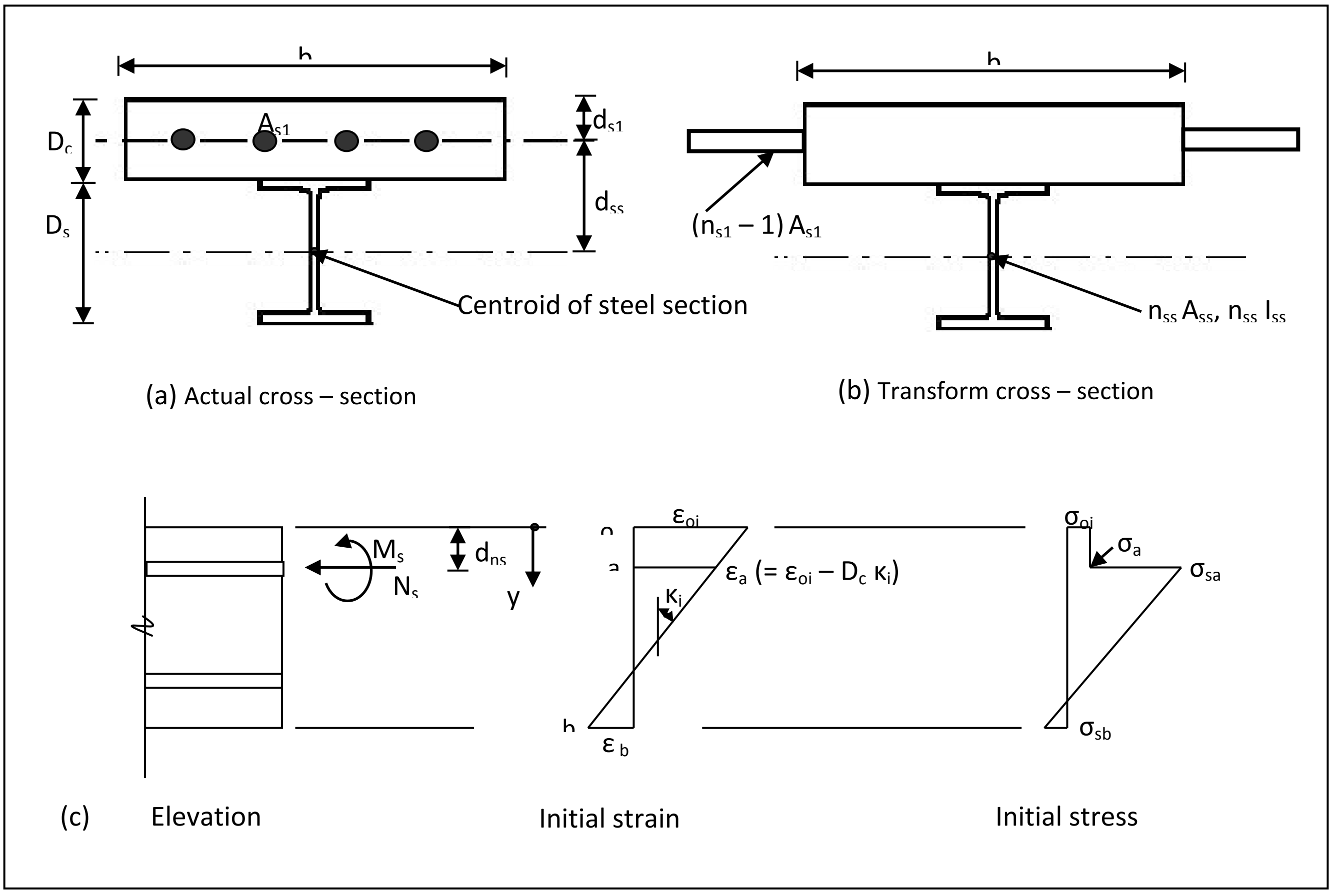


Figure 1. Actual and transformed composite section and initial stress and strain distribution[2,10]

1.2.2 Time Dependent Analysis[3]

The time–dependent behavior of the concrete is modeled using algebraic methods, such as the age–adjusted effective modulus method (AEMM), and the effective modulus method (EM). There is no different between them except in effective modulus ($\bar{E}_e$) calculation as mentioned before in Eqs. (2) and (4).

The resulting action – ΔN and – ΔM which are required to prevent the free development of creep and shrinkage in concrete deck are determined as follows:

$$-\Delta N = -\bar{E}_e\left[\Phi\left(A_c\,\varepsilon_{oi} - B_c\,\kappa_i\right) + A_c\,\varepsilon_{sh}\right] \tag{10}$$

$$-\Delta M = -\bar{E}_e\left[\Phi\left(B_c\,\varepsilon_{oi} - I_c\,\kappa_i\right) + B_c\,\varepsilon_{sh}\right] \tag{11}$$

As previously defined A_c, B_c and I_c are the properties of the concrete part of the cross – section, with respect to the top surface. The change of strain distribution with time can be calculated as follows:

$$\Delta\varepsilon_o = \frac{\bar{B}_e\Delta M + \bar{I}_e\Delta N}{\bar{E}_e(\bar{A}_e\bar{I}_e - \bar{B}_e^2)} \tag{12}$$

$$\Delta\kappa = \frac{\bar{A}_e\Delta M + \bar{B}_e\Delta N}{\bar{E}_e(\bar{A}_e\bar{I}_e - \bar{B}_e^2)} \tag{13}$$

The change of stress in the concrete deck at any point y below the top fiber may be obtained by the summing the stress loss due to relaxation and the stress caused by the application of ΔN and ΔM to the age – adjusted transformed section, as follows:

$$-\Delta\sigma = -\bar{E}_e \left[\Phi \left(\varepsilon_{oi} - y\,\kappa_i\right) + \varepsilon_{sh} - \left(\Delta\varepsilon_o - y\,\Delta\kappa\right)\right] \qquad (14)$$

As in the previous analysis, the time – dependent change of steel stress in the slab reinforcement and at any point on the steel I – section ($y > D_c$) is respectively:

$$-\Delta\sigma_{s1} = -E_{s1}\left(\Delta\varepsilon_o - d_{s1}\,\Delta\kappa\right) \qquad (15)$$

and

$$-\Delta\sigma_{ss} = -E_{ss}\left(\Delta\varepsilon_o - y\,\Delta\kappa\right) \qquad (16)$$

A-Barazanji(2) studied the structural behavior of composite steel-porcelinate reinforced concrete beams especially the short- term deflection and long-term deflection. The variable are, compressive strength ranging between (19.9 – 17.3 MPa) , degree of interaction 1.0, 0.8 , 0.5) and sustained uniform applied load (7 kN, 9 kN). A total of 8 composite steel- concrete are tested , six specimens are high- strength light weight concrete slabs , one is light weight concrete slabs and one normal weight concrete slab. The dimensions of all those concrete slabs of composite beams are 120x350 cross section area with 3000 mm span.

The results showed that the degree of interaction have also significant influence on the long-term behavior of the composite steel-high-strength procelinite reinforced concrete beams. When the degree of interaction decreased from (1.0 , 0.8 and 0.5) the maximum short –term mid span deflection increased about 64.6% and 37.5%, respectively, and the maximum long-term mid span deflection increased about 78.7% and 157.3% respectively at 270 day after loading. Other factors which influence the long- term behavior of the composite steel- procelinite reinforced concrete beams, is magnitude of the load sustain . Increasing sustained uniform applied load from 7 kN to 9 kN leads to increase in short- term deflection by 10.1% and increase in long- term deflection by 17.6%at 270 days after loading(2).

2. Experimental Work

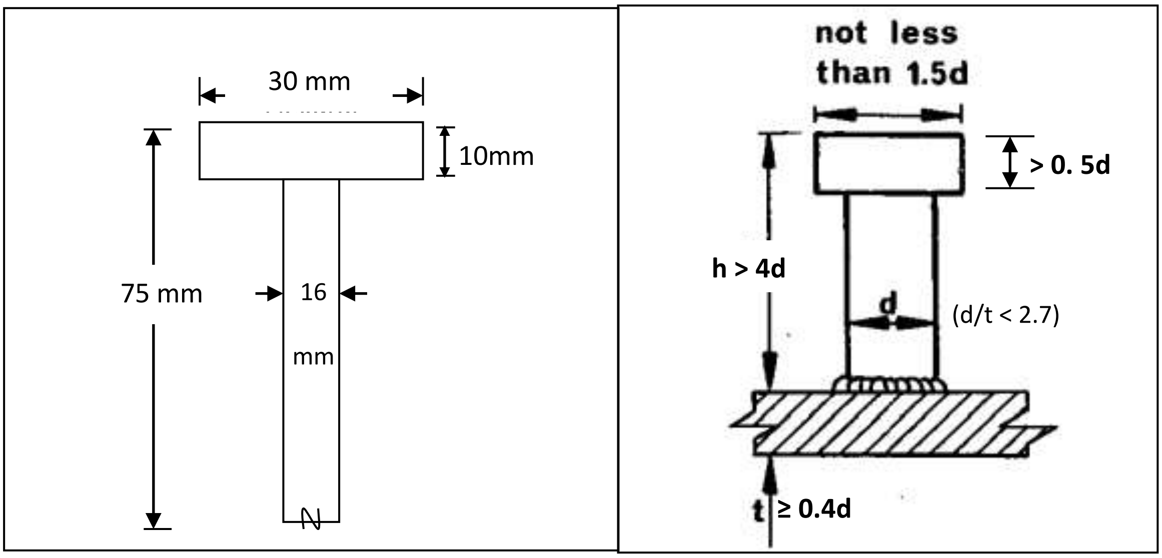
The experimental program consisted of casting and testing five composite beams with normal concrete. The tests were under simply supported conditions with uniformly distributed load . The span for all beams were 1750 mm with center to center 1500m. The concrete cross- sectional dimensions were (100x300) mm interconnected at their soffits to W12x35 sections by shear connectors . Headed stud , hooked stud smooth and deformed connectors are adopted as shear connectors between the layers. The main variables included the degree partial interaction and the type of shear connectors.

2.1 Shear Connectors

Shear connectors headed , hooked stud and channel, of details are shown in Table(1) and Fig(2), which satisfies the requirements of ASTM(A307)(11) and ASIC(I#.2d) requirements(12) were used.

Table(1) Details of shear connectors

Type of connector	Dimensions (mm)	
	Diameter	Length
Headed stud	16	75
Hooked stud smooth & defoemd	16	75



(a) Details of the headed stud connector used (b) Stud connecter size requirements [2,1]

Figure 2. Dimension of shear connectors

2.2 Steel beam section

The steel section was W12x35 , as shown in Fig(3) . Table(2) shows the geometry and dimensions of the steel section which satisfy the requirements of ASTM(A36)[11].

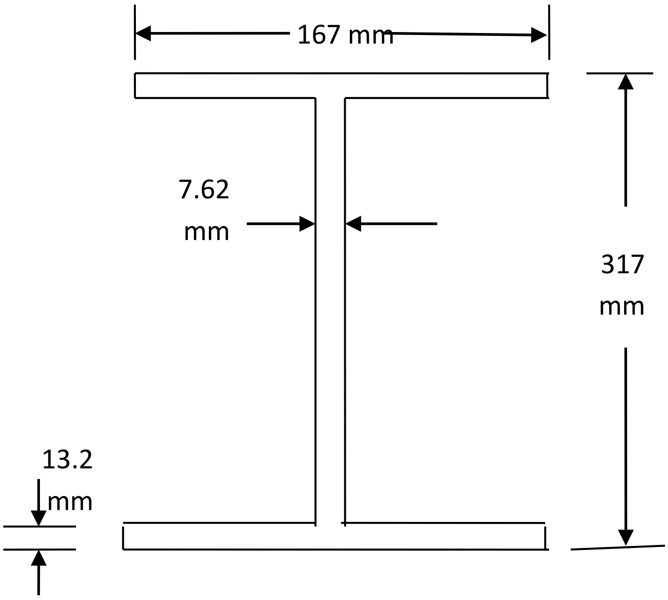


Figure 3. Details of (W12x35) steel section

2.3 Steel Reinforcement

Steel rebar Ø10 mm are used as secondary longitudinal reinforcement in the concrete slab which satisfy the requirements of ASTM(A615/A615M-01b) Grade 40[11].Table (2) shows the test results of steel reinforcement.

Table(2) properties of Steel Reinforcing Bar , Studs and Steel I-Section

Types of steel		Yield Stress (MPa)	Ultimate Tensile Strength (MPa)	Elongation(%)
Shear Connectors	Headed stud	613	741	13.0
	Hooked stud deformed	605	732	11.6
	Hooked stud smooth	510	703	11.4
Reinforcements (Ø10 mm)		622	710	13.0
W12x35		335	445	16.0

2.4 Concrete Mixes

Different trial mixes were made to conform specifications of normal concrete compressive strength according to ACI 211.iR. Different concrete specimens were casted and tested including slump , unite weight (fresh and hardened) , compressive strength , splitting tensile strength , flexural strength , static modulus of elasticity an shrinkage as shown in Table (3).

Table(3) Properties of concrete mix and specifications at 28 day

Test	Specifications	Results	Specimens
Slump (mm)	ASTM C143-05[15]	90-110	Cylinders (300x150) mm
Unit Weight (Density) kg/m3	ASTM C567-05[16]	2455- 2487	Cylinders (300x150) mm
Hardened unit weight kg/m3		2400-2425	Cylinders (300x150) mm
Compressive strength (MPa)	ASTM C39-01[17]	25.0 – 28.0	Cylinders (300x150) mm and 100 mm cubes
Splitting tensile strength (MPa)	ASTM C496-05[18]	2.15-2.276	Cylinders (300x150) mm
Flexural strength (MPa)	ASTM C78-05[19]	2.44-2.97	Prisms 100x100x500
Static modulus of elasticity (GPa)	ASTM C469-02[20]	21.5-22.7	Cylinders (300x150) mm
Shrinkage($x10^{-4}$)	ASTM C490-07[21]	0.051-0.50	Prisms 100x100x500

2.5 Composite Beams Details

The tests were done for five composite beams, details for the beams are shown in Figs(4) and (5) and Table(4) .

The steel section used are W12x35 , the concrete slab dimensions are 100x300 mm , the overall span length 1750 mm, with 1500 mm clear span. All beams were designed according to ASIC requirements[12] for composite steel concrete member (chapter I of the "specifications for structural steel Building"). The shear connectors were welded outstanding from the top flange of the steel section (as shown in Fig.(4)) and distributed in the spanwise direction.

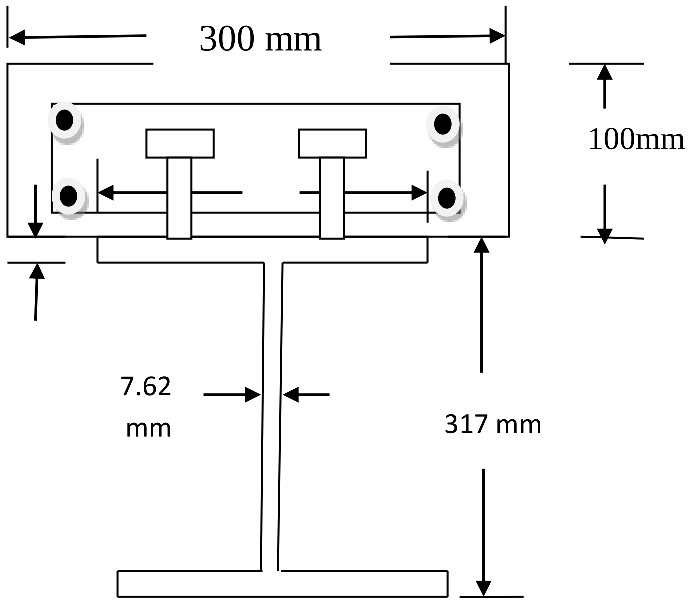


Figure 4. Details of cross section for the tested composite beams

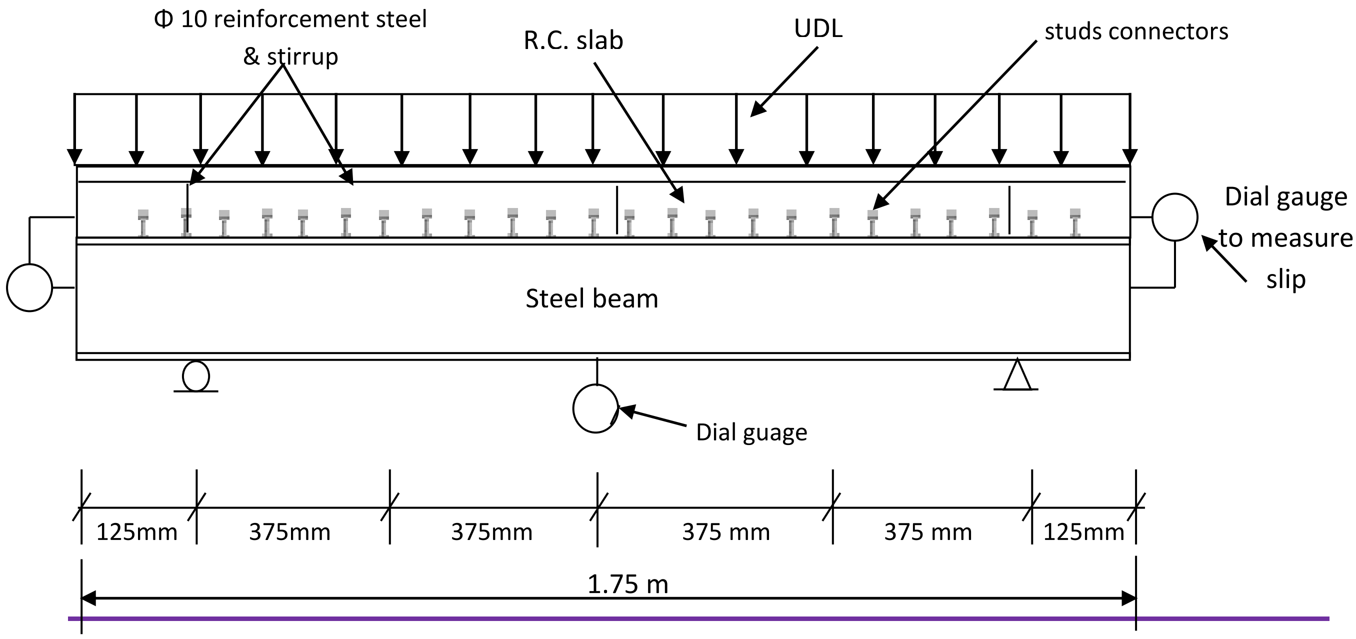


Figure 5. Test setup showing loading and measurements

Table(4) Details of Composite Beams

Beam symbol	Types of shear connectors	Degree of connectors	Arrangements stud per line	Distribution of shear connectors
B100H	Headed	100%	Pairs	@100 mm
B75H	Headed	75%	Pairs	@100 mm
B50H	Headed	50%	Pairs	@100 mm
B75LS	Hooked smooth	75%	Pairs	@100 mm
B75LD	Hooked deformed	75%	Pairs	@100 mm

3. Testing on Composite Beams

All composite beams are tested in the simply supported with 1.5 m center to center span . Measurement of deflections are done by dial gauges at mid- span of composite beams. These dials gauges with an accuracy of 0.01 mm. While measurement of relative displacement between layers (slips) are done by two dial gauges fixed at end of the beams between concrete slabs and steel section. Experimental results for the composite beams for maximum deflection (at mid-span) and maximum relative end slip at steel- concrete interface (at the two ends) are shown in Table(5) and (6), respectively.

Table(5) Experimental mid span deflection versus time

Time(days)	Deflections for Composite Beams (mm)				
	B100H	B75H	B50H	B75LS	B75HD
Instantaneous	0.65	0.72	0.91	0.71	0.58
28	0.75	0.84	1.06	0.83	0.66
56	0.79	0.88	1.15	0.85	0.77
90	0.89	0.99	1.21	0.91	0.86
120	0.95	1.08	1.33	1.01	0.95
150	0.96	1.21	1.44	1.13	1.06
180	0.97	1.31	1.61	1.22	1.15

Table(6) Experimental Relative end slip (st steel – concrete interface) versus Time

Time (days)	Slip for Composite Beams (mm)				
	B100H	B75H	B50H	B75LS	B75HD
Instantaneous	0.00	0.11	0.21	0.10	0.09
28	0.05	0.21	0.33	0.23	0.15
56	0.17	0.42	0.66	0.32	0.29
90	0.29	0.58	0.71	0.51	0.41
120	0.35	0.66	0.83	0.60	0.52
150	0.44	0.71	0.99	0.68	0.59
180	0.49	0.83	1.04	0.79	0.73

3.1 Effect of Degree of Interaction

3.1.1 Deflections

Figure(6) shows the comparisons of the time – deflection curves beams. Those beams are of the same properties and , but for different degrees of interactions 100, 75 and 50% .The instantaneous deflection of composite beams for 100% interaction was lower than the deflection of 75%, and 50% by 10.7% and 40% , respectively, while the deflection for B100H(100% interaction) was 35.05% and 65.97% lower than those of B75H and B50H , respectively due to decrease of stiffness.

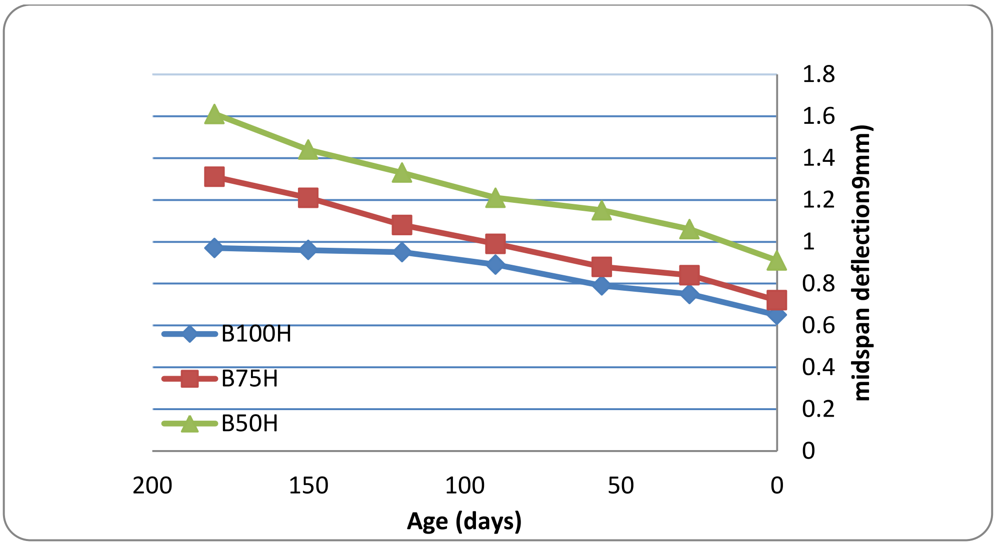


Figure 6. Deflection – Time relationship for composite steel- concrete beams of Headed studs with different degrees of interaction

3.1.1 Slip

Figure(7) shows the comparisons of the time versus relative end slip curves for the three composite beams. Value of that specified response for composite beam B100H is lower than the corresponding ones of B75H and B50H by 11% and 21%, immediately and 38.7% , 112.26% after 180 days, respectively, due to softening of interaction at interface of beams B75H and B50H as compared with the high degree of interaction of beam B100H which prevent any slip between the steel I-section and the concrete slab.

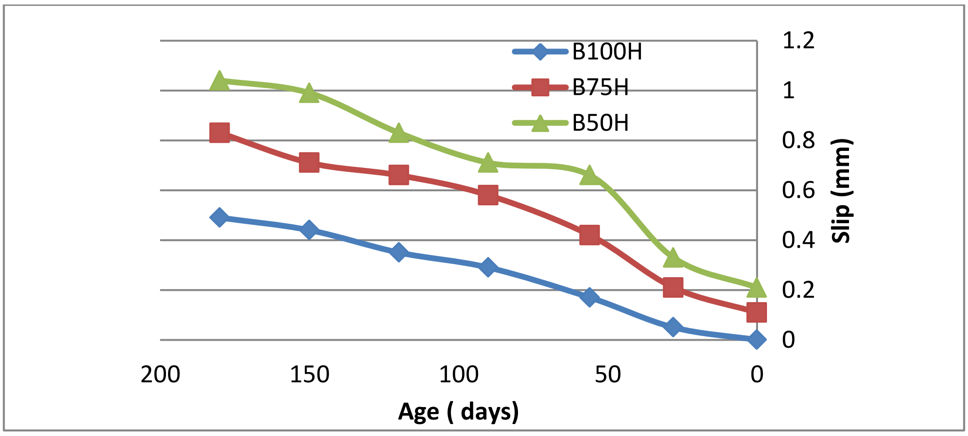


Figure 7. Slip – Time relationship for composite steel- concrete beams of Headed studs with different degrees of interaction

3.2 Effect of the connector type

3.2.1 Deflection

Figure(8) shows the comparisons of the time- deflection curves for the three composite beams (B75H , B75LS and B75LD) according to the type of connectors. Those beams are of the same properties , but for beam B75H used headed stud , B75LS used smooth hooked stud and for B75LD used deformed hooked stud , all beam with same degrees of interaction which is 75%.The instantaneous deflection of composite beams B75H is larger than those of B75LS and B75LD by 1.38% and 19.44%, respectively . IT then further increased with time till the increased percentage becomes 6.87% and 12.2%, respectively after 180 days. Changes in the deflection value were limited due to using the same geometry and concrete mix, size and geometry of the shear connectors did not affect the deformations announced by deflection and relative slip .

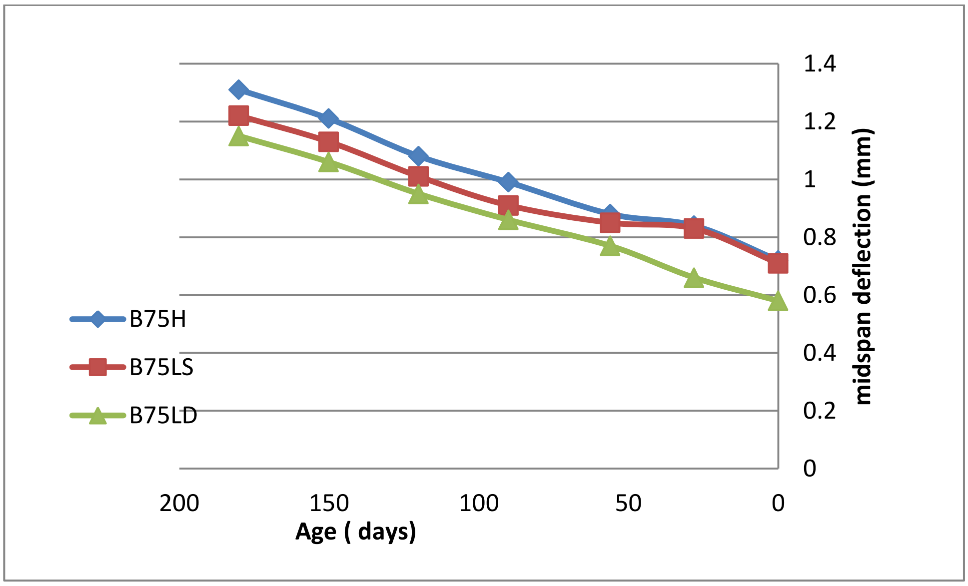


Figure 8. Deflection – Time relationship for composite steel- concrete with different shear connectors

3.2.2 Slip

Figure(9) shows the comparisons of the slip-time curves for the three composite beams B75H, B75LS and B75LD . Those beams are of the same propertied expect that each beam used different types of shear connectors. The instantaneous end slip of beam B75H was larger than those for beams B75Ls and B75LD by 9.09 % and 18.81%, respectively. After 180 days, the percentage decreased to 4.81% and 12.04%, respectively

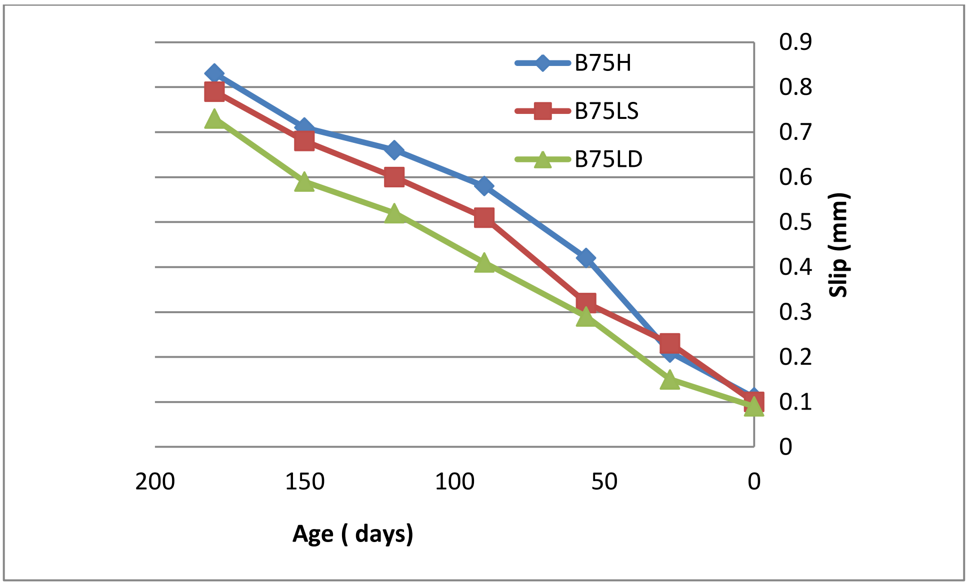


Figure 9.Slip – Time relationship for composite steel- concrete with different shear connectors

Conclusions

Based on the experimental results of this research the following conclusions have been made:

1. For certain type of shear connectors (Headed stud), when the degree of interaction decreased from 100% to 75% then to 50% the maximum long-term mid span deflection increased about 40% and 26.63 %, respectively at loading instant and 35.1% and 65.9%,respectively at 180 days after loading due to loss of interaction between layers.
2. Also for certain type of shear connectors (Headed stud) , the end slip increased about 67.5% and 112.4%, when shear connections reduced to 75% and 50% respectively at 180 days after loading.
3. Geometry and orientation of the shear connectors has slight effect on the slip and deflection, for 75% degrees of interaction using headed and hooked studs smooth or deformed the maximum long-term mid span deflection decreased about 7.1% and 11.7%at 180 days after loading, and the end slip decreased about 4.8% and 12.5% at 180 days after loading .

Notation

4. **A** area of transformed section
5. A_{ss} is the cross sectional area of the steel I – section
6. **B** the first moment of area of the transformed section about the top
7. E_c elastic modulus of the concrete
8. **I** the second moment of area of the transformed section
9. I_{ss} the moment of inertia of the steel I–section about its own centroid.
10. n_{s1} are the modular ratios for the steel reinforcement (E_{s1}/E_c)
11. n_{ss} are the modular ratios for the the steel I – section (E_{ss}/E_c),.
12. N_i the resultant axial force on the transform section ($N_i = N_s$) and
13. M_i the resultant moment about the top of the section ($M_i = M_s – N_s d_{ns}$)
14. t loading time
15. t_0 final time
16. $\varphi(t,t_0)$ creep coefficient
17. φ creep coefficient and
18. ψ aging coefficient

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