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BEHAVIOR OF STEEL-NORMAL AND HIGH STRENGTH CONCRETE COMPOSITE BEAMS WITH PARTIAL SHEAR INTERACTION

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ABSTRACT

In this research, aimed to study the behavior of simply supported steel concrete composite beams with normal and high compressive strength of the concrete slab under the action of a span mid-point external load. The steel I-section beam is located at the bottom of reinforced concrete slab and connected with it by stud shear connectors. Eight composite beams were tested under the action of a monotonic load, half of them had a normal strength concrete slab while the others with a high strength concrete slab. Four degrees of shear connection interaction (100%, 80%, 60%, and 40%) were used for both groups of the tested beams. It was noticed that there are no essential differences between the modes of failure that occurred in the tested beams with normal strength concrete and those with high strength concrete. It was also found that there is an increase in the initial stiffness of the beams when the concrete changed from normal to high strength for different degrees of shear connections, but this increment reduced with increasing the degree of the shear connection. It was noted that the ultimate capacity of the tested beams was increased with enhancement of the strength of the adopted concrete from normal to high strength. The results showed that, when the concrete compressive strength was increased from 32.6 MPa to 72.8 MPa, the ultimate moment capacity of the specimens was increased from 28% for 100% shear connection, and it is increased to 38% for specimens with 40% shear connection.

KEYWORDS: Composite beam, High strength, Degree of shear connection, Interaction, Concrete design

سلوك العتبات المركبة من الحديد والخرسانة الاعتيادية والعالية المقاومة ذوات اتصال قص جزئي

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الملخص

يتناول هذا البحث دراسة تجريبية لمعرفة سلوك العتبات المركبة ذات الاسناد البسيط وذات بلاط خرساني اعتيادي وعالي المقاومة معرضة لحمل خارجي مركز في منتصف طول العتبة ، تتكون العتبة من عارضة حديدية ذات مقطع I تقع في الجزء السفلي من البلاط الخرساني ومرتبطة معا بوصلات القص. تم صب ثمان عينات من العتبات الحديدية -الخرسانية المركبه حيث ان نصف النماذج يحوي خرسانة اعتيادية NC والبقية تحوي خرسانة عالية المقاومة HC. تم استخدام درجات تداخل قص (100٪، 80٪، 60٪، 40٪) لكلا النوعين من العتبات المركبة. وجد خلال فحص النماذج انه لا توجد اختلافات جوهرية بين انماط الفشل التي ظهرت في اختبار NC وHC. كما وجد ان صلابة العتبات المركبة ذات نفس الدرجة من الاتصال تتغير تبعا لنوع البلاطة الخرسانية. أظهرت النتائج عند زيادة مقاومة الخرسانة من 32.6 MPA الى 72.8 MPA يؤدي الى زيادة المقاومة القصوى للعتبات المركبة من 28% للنماذج ذات اتصال قص 100% الى 38% لذوات اتصال قص 40%.

1. INTRODUCTION

The expression "composite structure" is ordinarily comprehended inside the setting of structures and other building to infer the utilization of steel and concrete together into a part in a manner that the subsequent course of action capacities as a solitary thing. The point is to accomplish a more elevated amount of execution than would have been the situation had the two materials worked independently. Composite activity is accomplished by utilizing shear connectors mechanism. The shear connectors are typically joined to the top of a steel member by welding to transfer shear stresses between steel and concrete such that they will behave as one unit. Because of the composite activity, a huge increment in resistance and stiffness of the beams is obtained; this will reduce the depth of construction. In this way, composite beam is the main decision for long span structures with heavy applied loads giving the chance to accomplish an adaptable floor outline for the reception of evolving requests. With the approach of superior materials in composite beam these points of interest are used as advantage.

Nie et al., 2004, presented an experimental study on the structural behavior of steel high strength concrete composite beams with full shear connection between the two parts of the composite beams, steel section beam and the high strength concrete slab. Eight specimens were tested in this study, seven of them with high strength concrete and one with normal strength concrete. This study showed that the tested beams with high strength concrete have several favorable design aspects such as a larger margin beyond the steel yield and greater ultimate deformability. Battini et al., 2009, produced a nonlinear finite element analysis to study the effect of interlayer slips for two-layer composite plane beams. This finite element formulation was based on a previous exact solution of the governing equations for composite beams with deformable connectors. Sallam et al., 2010, studied experimentally the flexural behavior of strengthened steel concrete composite beams taking into account the effect of pre-intermediate separation between the steel beam and the strengthening materials. Two methods of steel strengthening were adopted, the use of carbon fiber reinforced polymer (CFRP) and the use of welded steel plate. They concluded that the pre-intermediate separation has no growth up before yield of the steel section, whereas the flexural capacity was reduced due to the rapid growth up of the intermediate separation between the steel beam and the strengthening sheets after yielding of steel section. Huiyong and Pradford 2013, provided results of fourty beams of high strength (HS) steel-concrete beams with steel of different types and different shear connection degrees. New design methodologies were planned so as to assessment the simply supported HS steel-

concrete beams behavior for bending, giving more dependable and economical design for such types of composite beams.

The present work studies the behavior of eight simply supported steel concrete composite beams with normal and high compressive strength of concrete slab, in which the structural steel I-section beam located at the bottom of reinforced concrete slab and connected with it by stud shear connectors. Different degrees of shear connection between the two parts of the tested composite beams were investigated, ranged from 40% to 100% for both types of these tested beams.

2. EXPERIMENTAL PROGRAM

2.1. Materials properties

The typical cross-section and the span length of all the tested beams are shown in Fig.1. Steel concrete composite beams were fabricated and then tested in this work. The properties of materials which used in the fabrication of the tested composite beams were including concrete, structural steel, reinforcement steel, and shear connectors.

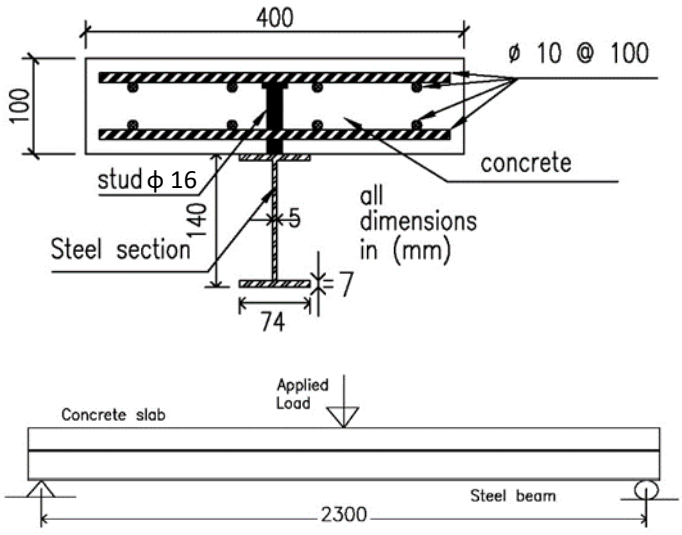


Fig. 1 Details of tested composite beams.

2.1.1. Concrete

In this experimental study, two types of concrete mix design are adopted, after many trail mixes, to produce normal compressive strength (NS) and high compressive strength (HS) for concrete slab of composite beams with same concrete slump value. The materials that used included ordinary Portland cement (OPC), crushed gravel (G), sand (S), water (W), Silica fume (SF) and

Superplasticizer (SP). The quantities of materials that is entered in the formation of the concrete are listed in Table 1. Table 1 also shows the compressive strength of cubes at 7-days and 28-days.

Table 1. Details and results of concrete mixes.

Concrete Mix Design	OPC (kg)	G (kg)	S (kg)	W (kg)	SF (kg)	SP (liter)	Slump (mm)	Density (kg/m^3)	Cube Compressive Strength (MPa)	
									7-day	28-day
NC Beams	415	1300	700	180	---	----	110	2410	23.7	33.2
HC Beam	460	1000	800	145	45	11.3	110	2435	58.8	73.1

All materials weights are for one cube meter of concrete mixture.

2.1.2. Structural steel I-section

The hot rolled steel I-section which is used in this work has dimensions of (140 mm outside height, 74 mm top and bottom flange width, 7 mm top and bottom flange thickness and 5 mm web thickness and with 13.1 kg/m weight), which is available in local markets, as shown in Fig. 1. The specimens for tensile test were cut from flange and web of I-section steel beam and the results of test are shown in Table 2.

Table 2. Tensile test results of I-section steel beam.

Test Specimen Location	Flange	Web	Average Value	ASTM A 36/A 36M
Yield Stress (N/mm^2)	367.7	372.5	370	250 Min
Ultimate Strength (N/mm^2)	480.3	479.5	480	400-550

2.1.3. Steel reinforcement bars

The steel reinforcement deformed bars with diameter 10 mm was used as shown in Figs.1 and 2. The test results of steel reinforcement specimen are shown in Table 3.

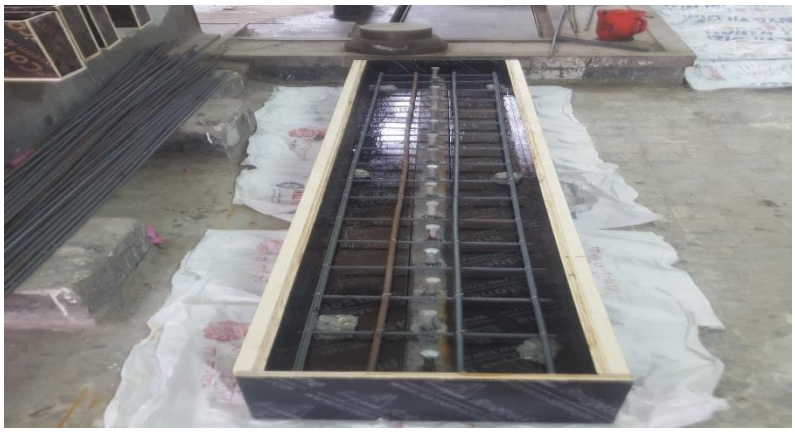


Fig. 2. Steel reinforcement of concrete slab of composite beam.

Table 3. Tensile test results of steel reinforcement specimen.

Item	Value	ASTM A 615/A 615M Requirements
Bar Diameter (mm)	10	-----
Yield Stress (N/mm^2)	465	420 Min.
Ultimate Strength (N/mm^2)	660	620 Min.
Elongation (%)	13	9 Min.

2.1.4. Stud shear connectors

The stud shear connectors with dimensions (75 mm height and 16 mm diameter), are joined to the top of a steel I-section by welding to transfer shear stress between two materials (concrete and I-section) making them as one units, as shown in Figs.2 and 3. Two specimens of stud connector were subjected to tensile test to get the yield stress and ultimate strength of stud material these values are given in Table 4.



Fig. 3. Instillation of stud shear connection.

Table 4. Tensile test results of stud shear connector.

Item	Value	ASTM A 307 Requirements
Stud Diameter (mm)	16	-----
Yield Stress (N/mm^2)	360	250 Min
Ultimate Strength (N/mm^2)	450	414 Min

2.2. Composite beams details

The total span length of tested specimens was 2.4m. These tested beams were designed according to the plastic analysis and design method that adopted by Eurocode 4. The reinforced concrete slab had dimensions of (100 mm depth and 400 mm width) and reinforced with two layers of rebar in two directions (Ø10 mm @ 100mm in each direction) as shown in Fig. 1. According to the plastic analysis, the required number of shear stud to get full interaction for the adopted composite beam cross section was equal to 20 studs (100% degree of connection) arranged with distance equal to 115mm along the beam length. The number of studs was reduced to be 16, 12, and 8 studs in order to get partial shear interaction with (80%, 60%, and 40%) degree of connection, respectively. In the design of the full shear connection composite beams sections for both normal or high strength concrete, the location of plastic neutral axis was kept in the concrete slab. Therefore, the distance between the stud shear connectors is the same for (NC) and (HC) as shown in Table 5. The 150mm cube compressive strength of concrete for each specimen is shown in Table 6.

Table 5. Distance of shear studs and degrees of connection of tested composite beams.

NC Beams	HC Beams	Number of Studs	Studs distance (mm)	Degrees of shear connection
NC040	HC040	8	300	40%
NC060	HC060	12	200	60%
NC080	HC080	16	150	80%
NC100	HC100	20	115	100%

Table 6. Compressive strength of concrete slabs of composite beams.

Concrete Slab	Composite Beam	Average compressive strength of 3 concrete cubes (MPa)		Average value of concrete compressive strength (MPa)
		7 days	28 days	28 days
Normal compressive strength	NC040	24.4	32.1	32.6
	NC060	25.1	34.2	
	NC080	24.4	31.0	
	NC100	24.9	33.1	
High compressive strength	HC040	57.6	71.1	72.8
	HC060	58.4	73.6	
	HC080	57.9	72.4	
	HC100	59.3	74.1	

2.3. Instrumentation and testing procedure

The deflections, applied loads, and slips between the steel I-section and the concrete slab were measured for all specimens. Monotonic loads were applied using Universal Testing Machine (TORSEE) 200 tons' capacity to all the tested specimens. The simply supported effective span for all tested beams was (2.3m) which loaded at mid-span as shown in Fig. 4. The applied load was increased successively up to failure. The measurements of the mid-span deflection, end slip, and crack development were recorded at the end of each load increment.



Fig. 4. Steel concrete composite beam specimen under test.

3. RESULTS AND DISCUSSION

3.1. Modes of failure

All the specimens showed flexural failure modes started by yielding the steel beam and then crushing of the concrete flange in the mid span. There were no essential differences in the stages of behavior between the specimens with normal or high strength concrete except that the steel beams of the specimens with high strength concrete exhibited to more stresses until yielding occur compared with the specimens with normal strength concrete. The crack patterns may considered as flexural cracks at the mid span of the tested specimens and a shear flexural cracks beyond the mid span region, in spite of that the intensity of cracks in the HC specimens was slightly more than that appeared in the NC specimens as shown in Fig. 5. There was no separation (uplift) appeared between the concrete flange and steel beam for all the tested specimens.

3.2. Load deflection response

The experimental results for testing of all the specimens are summarized in Table 7. The load mid-span deflection curves for the tested NC and HC specimens are shown in Figs. 6 and 7, respectively.

For both NC and HC specimens, the load deflection curves can be divided into two stages. The first stage corresponded to the linear elastic response of the tested specimens. This stage was continued until the load reached about 45 – 50% of the ultimate load for NC specimens and about 60 – 65% of the ultimate load for HC specimens. Also, it was noted at this stage that there was an increase in the stiffness, which represented by the slope of the linear part of the curves, when the concrete was changed from normal to high strength for different degrees of shear connections. But this increment in the stiffness reduces with increasing of the degree of the shear connection, as shown in Figs.8 and 9. The second stage represents the response of the tested specimens beyond yielding of I-section, where the behavior became nonlinear and the stiffness gradually degraded until failure. The length of this part of the load deflection curve is reduced compared with the linear part as the degree of shear connection increased for both NC and HC specimens, in spite of that this nonlinear stage is appeared clearly in the responses of the HC specimens if compared with the response of the NC specimens.



Fig. 5. Mode of failure and crack pattern for tested specimens.

Table 7. Experimental test results for all tested specimens.

Beam No.	NC40	NC60	NC80	NC100	HC40	HC60	HC80	HC100
Failure Ultimate Load (kN)	109.8	131.4	147.4	159.1	151.7	176.8	193.9	203.7
Max. Deflection (mm)	23.2	19.7	16.9	15.4	27.1	21.6	17.3	14.9
Service Load (kN)[a]	73.2	87.6	98.3	106.1	101.1	117.9	129.3	135.8
Deflection at Service Load (mm)	8.2	7.5	5.9	5.7	6.5	6.6	6.2	5.9
Beam Stiffness (kN/mm)[b]	8.93	11.68	16.66	18.61	15.56	17.86	20.85	23.02
End Slip (mm) at ultimate load	4.470	2.180	1.590	1.260	3.130	1.680	1.170	0.900
Ultimate Moment Capacity (kN.m)	63.14	75.56	84.76	91.48	87.23	101.66	111.49	117.13

a) the service load is represented as two third of ultimate load (Abbas A. M. and Resan S.F).
b) beam stiffness is evaluated by dividing the service load on the corresponding deflection.

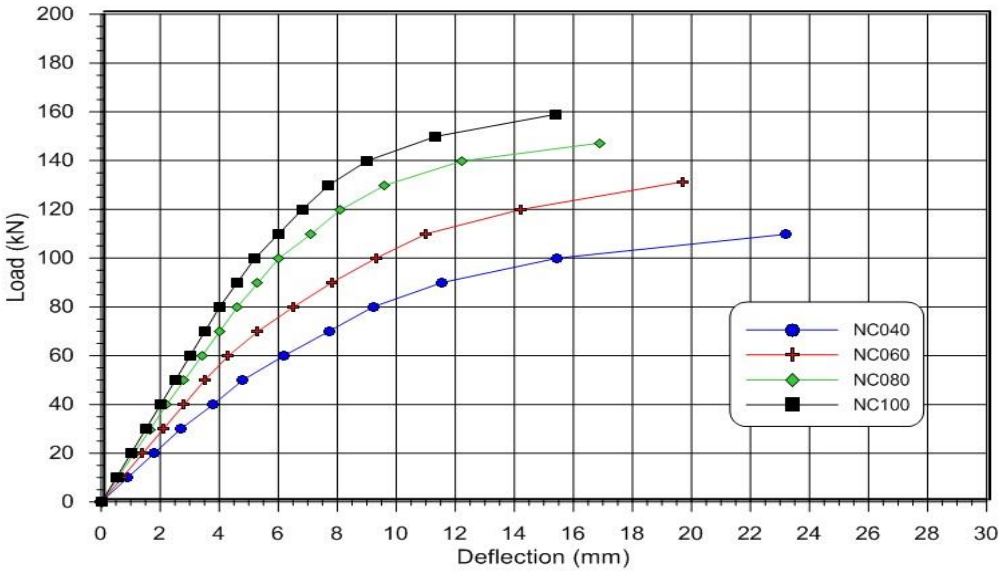


Fig. 6. Applied load – midspan deflection relationships for tested NC beams.

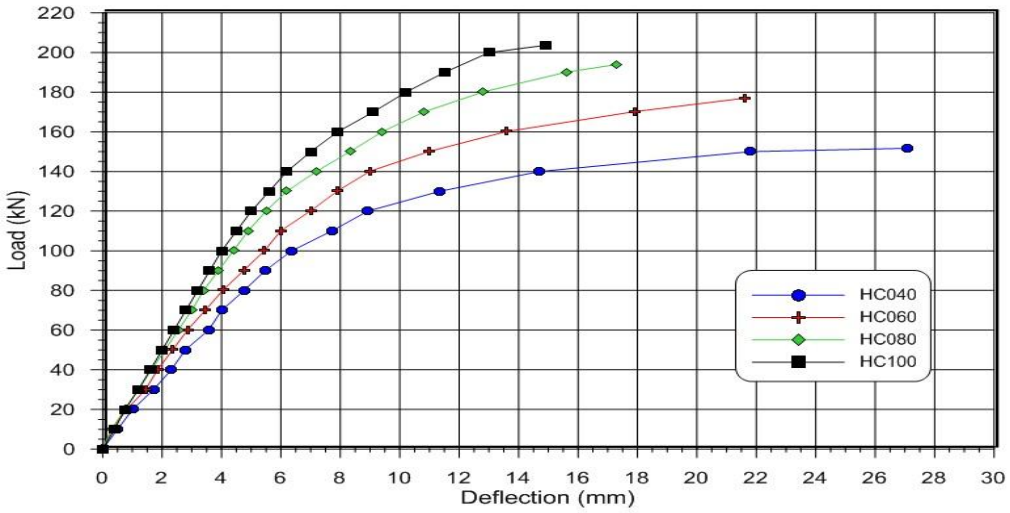


Fig. 7. Applied load – midspan deflection relationships for tested HC beams.

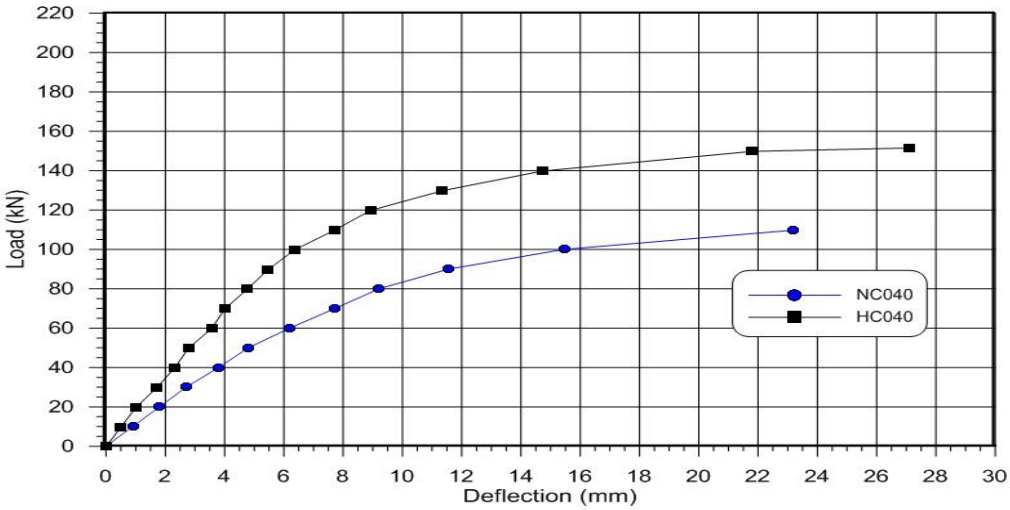


Fig. 8. Behavior comparison between NC and HC tested beams with 40% shear connection.

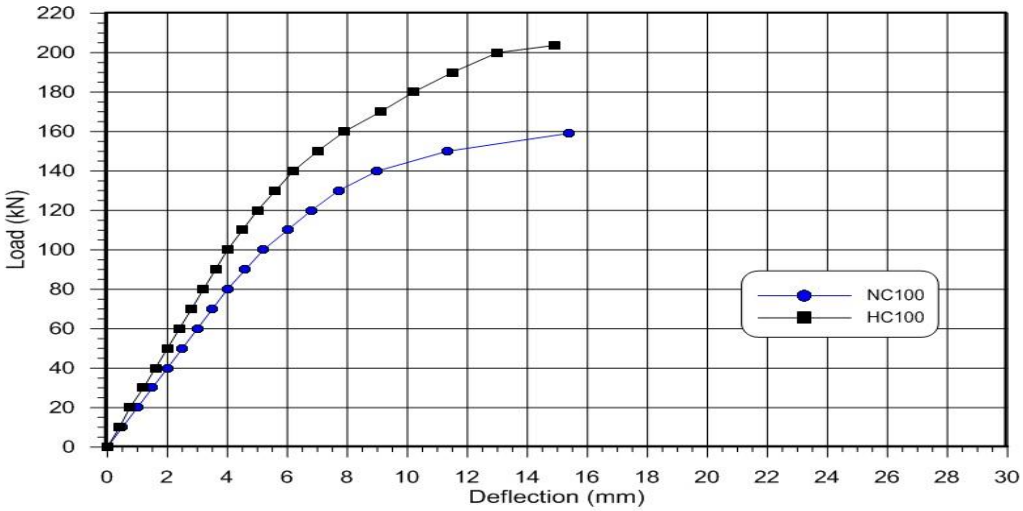


Fig. 9. Behavior comparison between NC and HC tested beams with 100% shear connection.

3.3. Ultimate strength

The experimental results clearly show, and as expected, that the degree of shear connection increases, the ultimate strength of the steel concrete composite beams increases, approximately in the same manner for both NC and HC, as shown in Fig. 10. On the other hand, the ultimate strength of the tested specimens was increased with enhanced the increment of the strength of the concrete. When the compressive strength increased from 32.6 MPa to 72.8 MPa, the ultimate moment capacity of the specimens was increased by about 28% for specimens with 100% shear connection and 38% for specimens with 40% shear connection.

3.4. End slip

Fig. 11 and Fig. 12 show the relative end slip (Johnson R.P.), between the steel beam and the concrete flange for the tested beams for different load levels for NC and HC specimens, respectively. Also, Table 7 shows the values of the end slip for all the tested specimens corresponding to the ultimate load. It is clearly appeared, and found as expected, that end slip value decreased with increasing the degree of shear connection. But it was noticed that the measured end slip for the beams with HC gives smaller values for different degrees of shear connection compared with those obtained from the tests NC, as shown in Figs. 13 and 14.

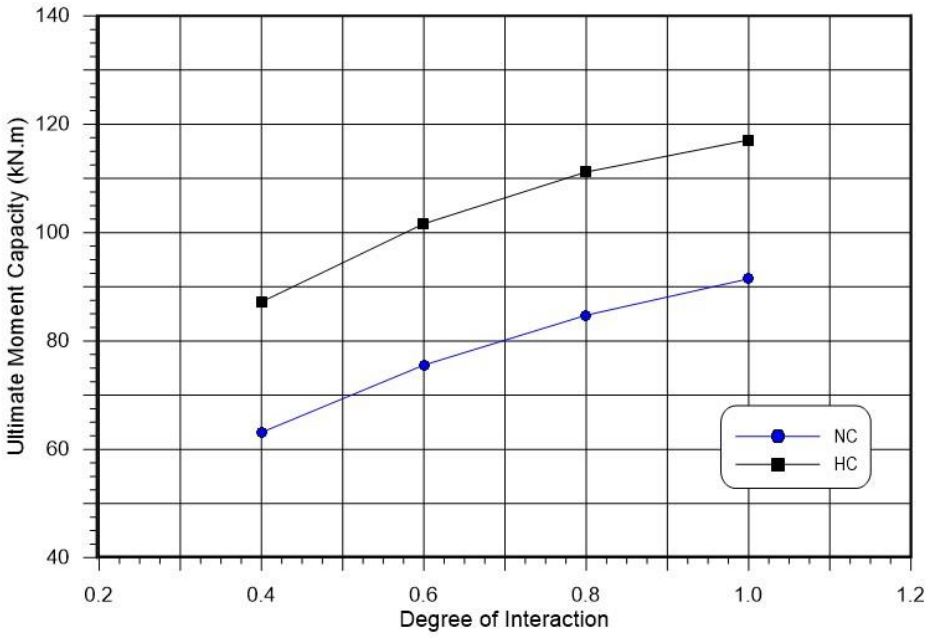


Fig. 10. Variation of ultimate moment capacity with degree of shear connection for NC and HC beams.

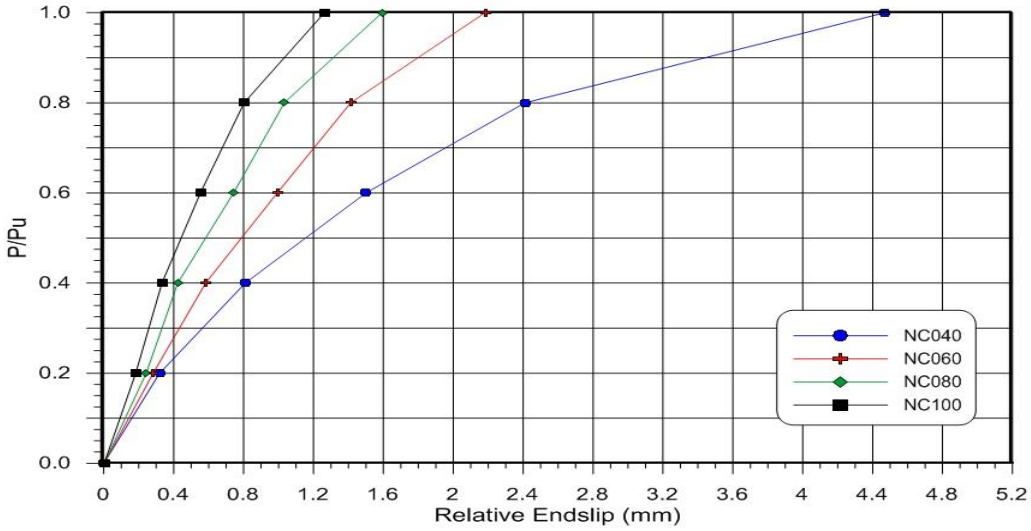


Fig. 11. Variation of end slip with applied load for NC beams.

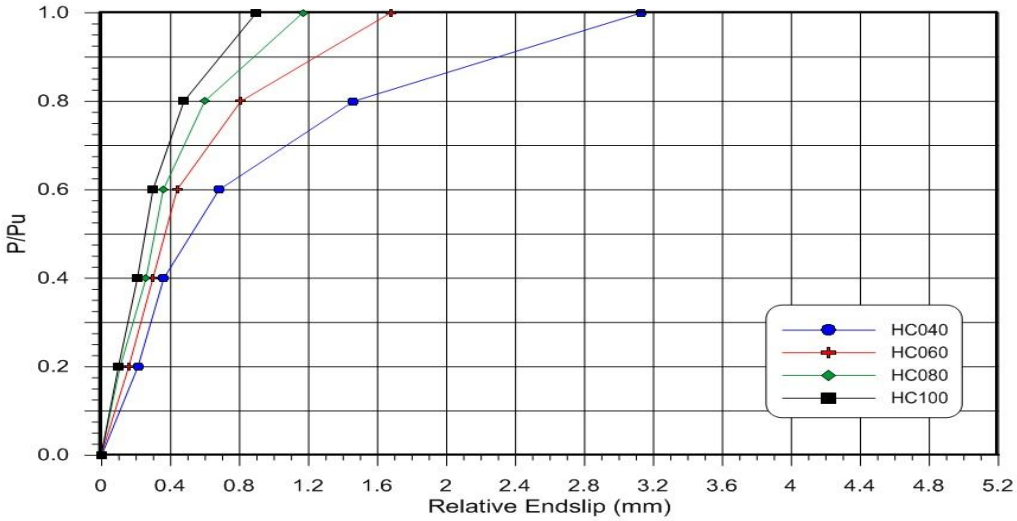


Fig. 12. Variation of relative end slip with applied load for HC beams.

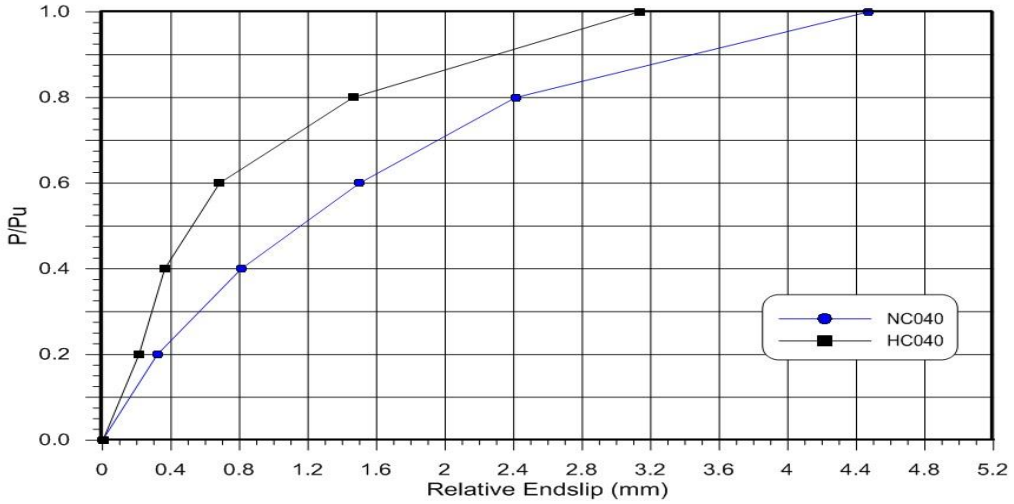


Fig.13 Effect of concrete strength on the variation of relative end slip beams of 40% shear connection

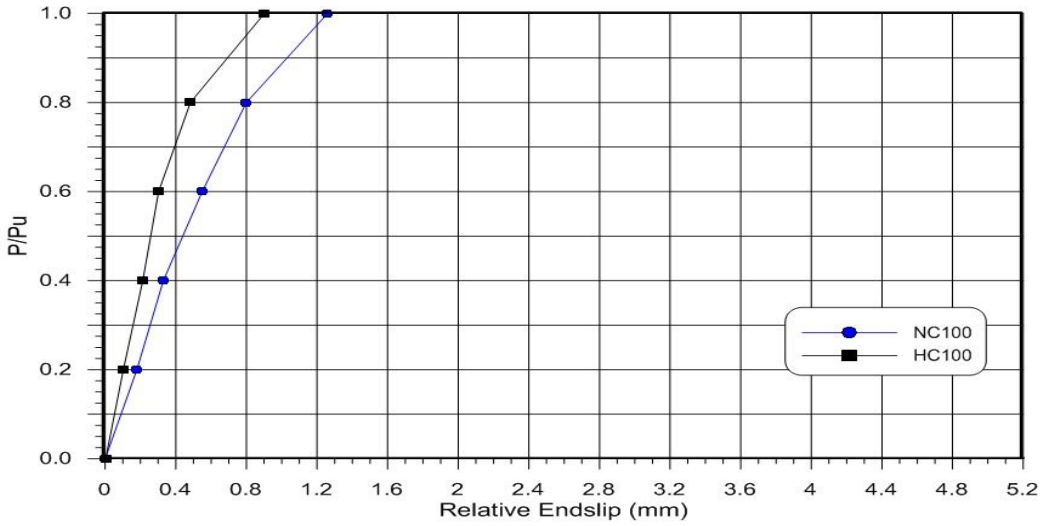


Fig. 14. Effect of concrete strength on the variation of relative end slip beams of 100% shear connection.

4. CONCLUSIONS

Experimental study was carried out of eight steel concrete composite beams in order to investigate their structural behavior with the effect of the degree of shear connection and the compressive strength of concrete slab. Four of the tested beams were fabricated with normal compressive strength concrete slab and the others with high compressive strength concrete slab. It was concluded that;

- There were no essential differences between the failure mode that found in the tested NC and HC slabs.
- The initial stiffness of the beams was increased with changing the concrete slab from normal to high strength.
- As expected, with the increase of the degree of shear connection (increase the number of welded shear studs), the ultimate strength of beams increased approximately in the same manner.
- The measured end slip for beams with HC had small values for different degrees of shear connection compared with values obtained from the tests of beams with NC.

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