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***Research paper***

# Effect of Angle Shear Connectors on the Behavior of Composite Concrete Steel Flexural Members Under Negative Moment

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**Abstract**

This research presents an experimental program to study the effect of using angle shear connectors instead of the headed stud on the flexural behavior of composite beams under negative bending moment (NBM). Both the angle and headed stud shear connectors used in this study have the same cross-sectional area. Five composite beams were casted and tested using three-point load configuration to ensure the NBM effect. Different parameters were included in this study such as the type of shear connector, bond interaction (partial and complete bond interaction) and arrangement of angle shear connectors. Two proposals method were suggested for angle setting in this study to investigate the structural behavior of the composite section. It has been found that, in the case of single angle shear connectors, the ultimate strength decreased by 4.12% compared with samples with the headed stud shear connectors. The direction of the angle setting has been shown to affect the flexural behavior of the composite section.

***Keywords***: *Angle shear connectors; Bond interaction; Composite section; Negative moment; Shear connectors.*

## 1. Introduction

Composite member, generally, is a combination of two or more elements. The bond between these elements is the key that controls the performance of the composite member. Different techniques are used to ensure an adequate bond strength. In steel-concrete composite member, the longitudinal shear forces are transferred through the bond region using shear connectors. These connectors when used restrain the shear flow in the interface region. Therefore, in composite members, the selection of adequate shear connectors is dictated by the transfer of the maximum shear force.

In industry, different geometries of shear connectors are available. The most preferred connectors are angle shear connectors since the C-shaped shear connectors are available in different standard sizes for hot rolled steel. Additionally, they can be easily produced in a simple way by cutting their long steel profile. Different factors can affect the shear connector performance and govern the mutually interactive response of the connector and the surrounding concrete.

Choi et al. (2008) [1] conducted an experimental program and finite element analysis (FEA) to investigate the fatigue strength of welded joints between angle shear connectors and the bottom plate in steel-concrete composite slabs. Stoy and Shima (2011) [2] compared the results of experimental with FEA results for beam type specimens with L-shape shear connectors. These connectors were installed and subjected to a strut compressive force. Different parameters were selected and include the FEA such as the strength of the used concrete, shear connectors size, and the strut angle.

Shariati et al. (2014) [3] investigated the angle shear connectors embedded in high strength concrete (HSC) slab behaviour experimentally using push-out specimens. Different geometries of angle shear connectors were included in this study. Mazoz et al. (2013) [4] summarized the results of new type I-shaped shear connectors using push-out test specimens. Different parameters were included and studied in this test such as the shear connectors height and length, concrete compressive strength, and the transverse bar reinforcement numbers.

Shariati et al. (2014) [5] applied a fully reversed cyclic fatigue load on push-out specimens to study the fatigue energy dissipation of angle shear connectors embedded in HSC slab. The angle shear connectors failure under monotonic and low cyclic fatigue loading was discussed.

Khorramian et al. (2017) [6] conducted a push-out test to investigate the ultimate load capacity of tilted-shapes angle shear connectors behaviour under monotonic load. The angles between the steel beam and the angle shear connector leg were 11.2o and 135o with different angles' lengths and sizes.

Nouri et al. (2016) [7] conducted an experimental study to investigate the behavior of a newly proposed shear connector i.e. stiffened angle shear connector at an elevated temperature. This study was adopted to describe a finding on shear resistance of the stiffened angle shear connectors subjected to isothermal fire loading. Eight push-out specimens were tested covering various geometries of stiffened angle shear connector.

Shariati et al. (2016) [8] conducted push-out tests to compare the channel and angle shear connectors performance embedded in HSC composites. The shear resistance and ductility of the two types of connectors were primarily investigated using static and cyclic loadings.

Tahmasbi et al. (2016) [9] investigated the behavior of two shapes of angle shear connectors (C and L-shaped) embedded in solid concrete slabs experimentally and numerically. Finite element model

(FEM) was built to simulate the behavior of these connectors by employing nonlinear behaviour using large displacement and damage plasticity. Different parameters were included in the FEM such as concrete compressive strength and connectors' dimensions.
Zhang and Zhang (2016) [10] presented an experimental research on the capacity of angle shear connectors. Six push-out specimens with different height and thickness of angles were included in this experiment. The failure mode observed in all specimens was the concrete crushing splitting.
Khorramian et al. (2017) [11] investigated numerically the behavior of tilted angle shear connectors embedded in solid concrete slabs. Two different tilted angle connectors were used, titled angle with 112.5 and 135 degrees between the angle leg and steel beam flange. A nonlinear finite element model was developed to simulate and validate the experimental push-out tests.
The shear connectors design strength plays an essential role in the composite member's design. The design equations are available for some types of shear connectors in standard American Institute of Steel Construction (AISC) [12] code such as headed stud and channel. The other types of shear connectors such as angle, it is recommended by AISC to test these connectors as mentioned in AISC section (I9). Different experimental programs were used to evaluate the shear connector design strength such as push-out test specimens. In the present study, an experimental program is adopted to study the effect of use angle shear connectors instead of the headed stud on the flexural behavior of composite beam under NBM. Both the angle and headed stud shear connectors have the same cross section area.

## 2. Experimental program

The experimental work that carried out in this study is used to investigate the structural behavior of composite steel beams with angle shear connectors. The experimental work has been conducted at the laboratory of the College of Engineering, Al-Qadisiyah University.

### 2.1. Specimens details and tests setup

The experimental work included testing five composite I-sections hot rolled steel beams under NBMs with various types of shear connectors. All specimens are steel beams with section of (M4×3.2) according to AISC with length of (1100mm), these steel sections were composite with the reinforced concrete slab of (1100×400×80) mm. Concrete slabs were reinforced by using ordinary steel reinforcement (φ10mm) longitudinal and closed stirrups reinforcement, as shown in Fig. 1.

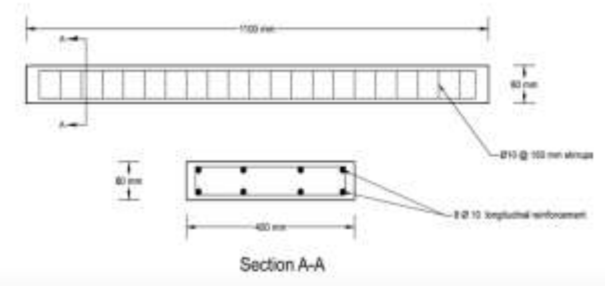



**Fig.** 1 Reinforcement of concrete slab

Two types of shear connectors (headed stud and angle shear connectors) were used and have the same cross sectional area. The adopted specimens were differed by the type of shear connector, bond interaction between concrete slab and steel beam, and arrangement of angle shear connectors where two proposals method angle setting were suggested in this research to investigate the structural behavior of composite section. Table 1 explains the geometrical details and specimen designation of steel beams that have been used in this study. Fig. 2 shows the specimens before and after casting of the concrete part.

**Table 1** Steel Beams Description, Designation, and Geometry

| Specimen Designation | Type of Shear Connector | Bond Interaction |
|---|---|---|
| C.B40.H1 | Headed Stud | Partial |
| C.B40.H2 | Headed Stud | Complete |
| C.B40.L1 | Angle | Partial |
| C.B40.L21 | Angle | Complete |
| C.B40.L22 | Angle | Complete |

Headed stud shear connectors were used in two specimens named (C.B40.H1 and C.B40.H2). The symbol (C) refers to the composite section, (B40) refers to slab width in centimeter, and (H1 or H2) refers to single or pair of headed shear connectors respectively, (i.e. to partial or complete bond interaction), as shown in Fig. 2.

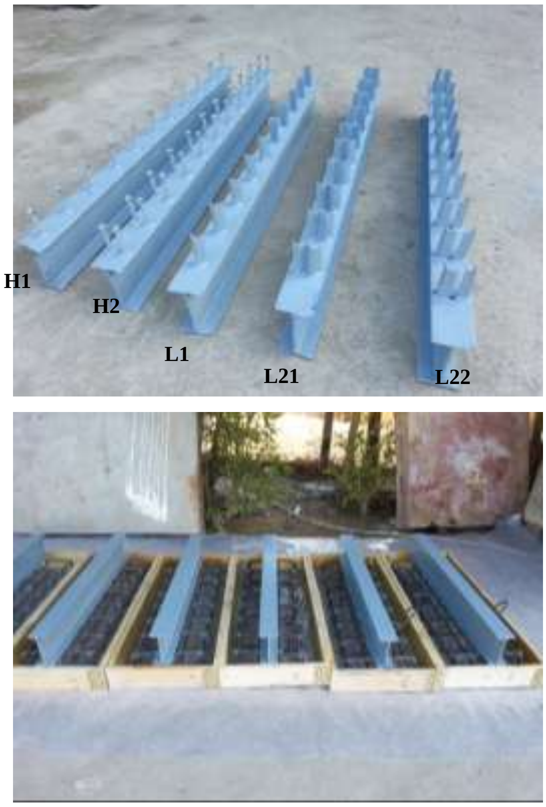



**Fig. 2:** Shear connectors and beam before casting

Angle shear connectors were used as an equivalent to headed stud which has the same cross section area. It is used in three specimens named (C.B40.L1, C.B40.L21 and C.B40.L22) where the symbol (L1) refers to single angle shear connector; (L21) refers to pair of angle shear connector welded to flange of steel beam as a proposal No.(1), and (L22) refers to pair of angle shear connectors welded to flange of steel beam as a proposal No.(2), as shown in Fig. 2.
Partial bond interaction refers to the use of single headed stud shear connector (φ7mm-L70mm @100mm) or single angle shear connector (L12.5×12.5×0.8) mm @100mm welded in the mid tension steel flange, while complete bond interaction refers to the use of pair headed stud or angle shear connector.

### 2.2. Loading and test procedure

A hydraulic machine of 300-kN capacity was used in the experimental program. The load case represented by beam under effect of NBM due to point load applied at the mid span of steel beam as shown in Fig. 3. All specimens were tested using three-point loading configuration with a 1000 mm clear span length. All specimens were loaded monotonically until failure.

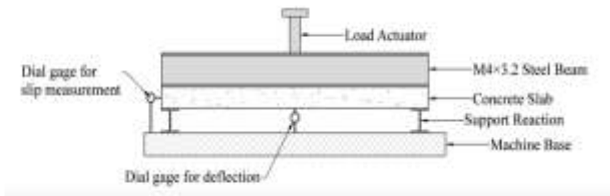



**Fig. 3:** Details loading, supports conditions and position of deflection measurement

# 3. Results and discussion

## 3.1. Failure and load- slip behavior

Load deflection relationship, failure pattern, and end slip of composite steel plate girders are recorded for all specimens and discussed in the following.

1. Specimen (C.B40.H1)

The load deflection relationship and load end slip of specimen (C.B40.H1) is shown in Fig. **4** and it can be observed that the ultimate strength of this specimen was (104.4 kN). Fig. **5** shows the failure mode of the adopted specimen with the crack pattern. The first crack was noticed at load level of 75.2 kN while the slip value of the end of the slab at ultimate stage was 3.75 mm.

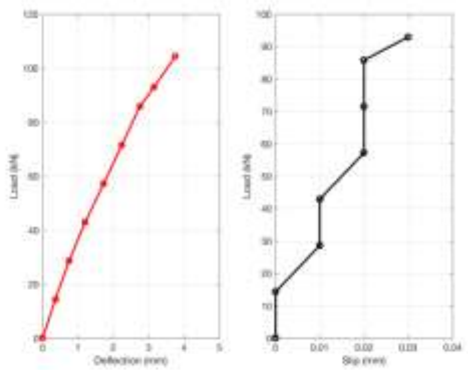


**Fig. 4** Load deflection and load slip relationships for specimen (C.B40.H1)


**Fig. 5** Failure mode of specimen (C.B40.H1)

2. Specimen (C.B40.H2)

Fig. **6** shows the load deflection and load end slip relationship for specimen (C.B40.H2). It observed that the ultimate strength of this specimen is (114 kN). Fig. **7** explains the crack pattern and failure mode of this specimen. It was observed that the first crack was observed at load level 71.5 kN. The slip at ultimate load level was measured and it was 0.08 mm.

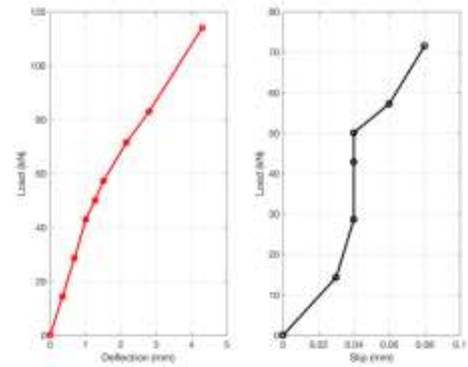


**Fig. 6** Load deflection and load slip relationships for specimen (C.B40.H2)


**Fig. 7** Failure mode and crack pattern of (C.B40.H2) specimen

3. Specimen (C.B40.L1)

The ultimate strength of this specimen was (100.1 kN) as shown in Fig 8 that represents the load deflection and load slip relationship for specimen (C.B40.L1). Fig. **9** shows the failure mode and the crack pattern of this specimen. It observed experimentally that the first crack was observed at load level of 50.5 kN. The slip of the edge of beam at the ultimate level was 0.03 mm.

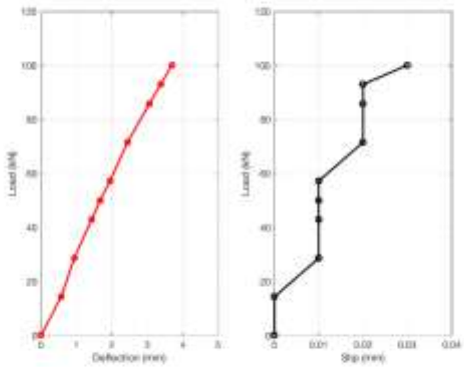


**Fig 8** Load deflection and load slip relationships for specimen (C.B40.L1)

**Fig. 9** Crack pattern and failure mode of specimen (C.B40.L1)

4. Specimen (C.B40.L21)

The load deflection curve and load slip curve for specimen (C.B40.L21) are shown in Fig. **10** and the ultimate strength of this specimen was (117.3 kN). The first crack was recorded at load level of 57.2 kN. The slip of the end slab at ultimate load level was recorded as 0.02 mm. Fig. **11** depicts the failure mode and the crack pattern and of this specimen.

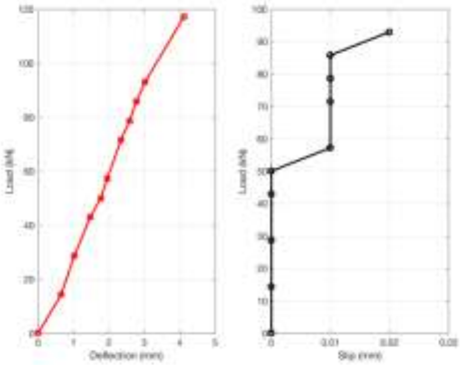


**Fig. 10** Load deflection and load slip relationships for specimen (C.B40.L21)

**Fig. 11** Failure mode and crack pattern of (C.B40.L21) specimen

5. Specimen (C.B40.L22)

For this specimen, the load deflection and load slip curves are shown in Fig. **12**. The ultimate strength of this specimen was (107.3 kN). The first crack was shown at load level of 57.2 kN. The final slip of the specimen end was recorded as 0.07 mm. Fig. **13** depicts the crack pattern and failure of this specimen.

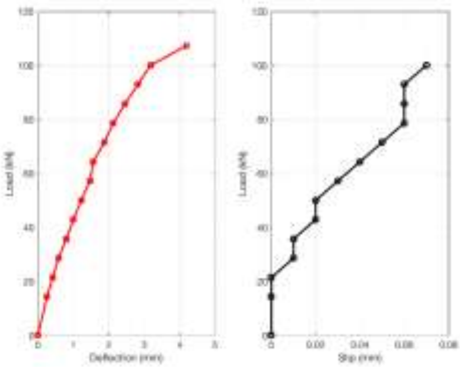


**Fig. 12** Load deflection and load slip relationships for specimen (C.B40.L22)

**Fig. 13** Failure mode and crack pattern of (C.B40.L22) specimen

Table 2 summarizes the experimental results and compares these results for all specimens in term of load and mid-span deflection. Failure mode of all specimens represented by concrete crack from upper stream and propagation through concrete layers until failure.

**Table 2** Ultimate load and midspan deflection of tested specimens

| Specimen | Pcr (kN) | Pu (kN) | Δcr (mm) | Δu (mm) |
|---|---|---|---|---|
| C.B40.H1 | 75.2 | 104.4 | 1.55 | 3.75 |
| C.B40.H2 | 71.5 | 114 | 2.16 | 4.3 |
| C.B40.L1 | 50.05 | 100.1 | 1.67 | 3.7 |
| C.B40.L21 | 57.2 | 117.3 | 1.95 | 4.12 |
| C.B40.L22 | 57.2 | 107.3 | 1.47 | 4.18 |

$P_{cr}$: Load at 1st Crack
$P_u$ : Ultimate load
$\Delta_{cr}$: Mid-span Deflection at 1st Crack
$\Delta_u$: Mid-span Deflection

## 3.2. Effect of shear connectors type

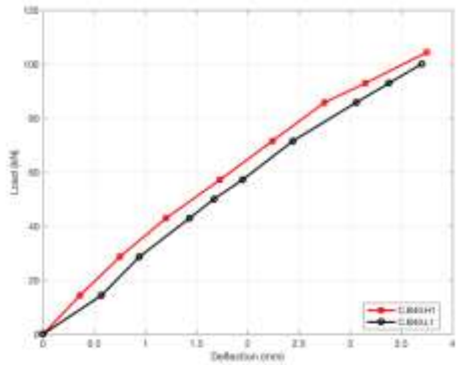
Equivalent cross section area of headed stud was used to get an equivalent angle shear connector. Composite concrete steel beam with various type of shear connector were tested to predict the behavior of composite section under NBM. Fig. **14**, Table **3** and Table **4** show the load deflection relationship and ultimate strength of composite section respectively for the adopted specimens.

**Table 3** Effect of shear connectors type (single shear connector)

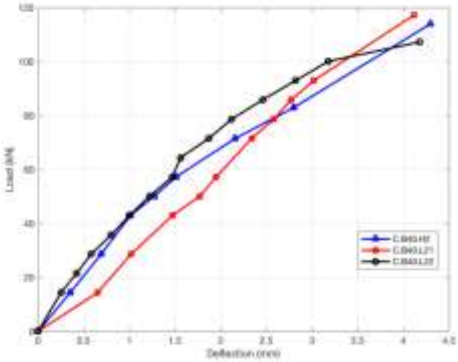
| Specimen | $P_u$ (kN) | Difference (%) |
|---|---|---|
| C.B40.H1 | 104.4 | - |
| C.B40.L1 | 100.1 | -4.12 |

**Table 4** Effect of shear connectors type (double shear connector)

| Specimen | Pu (kN) | Difference (%) |
|---|---|---|
| C.B40.H2 | 114 | - |
| C.B40.L21 | 117.3 | 2.89 |
| C.B40.L22 | 107.3 | -5.88 |



a- For single shear connectors



b- For double shear connectors
**Fig. 14** Effect type of shear connectors

From experimental results, it is observed that the ultimate strength decreased by a ratio of (4.12) % when the single angle shear connectors were used instead of headed stud. The same behavior for the second suggested arrangement of double angle shear connectors (C.B40.L22) was observed. The ultimate strength decreased by a ratio of (5.88) % than double headed stud. The ultimate strength was greater than double headed stud by (2.89) % when the first suggested arrangement of double angle shear connectors were used (C.B40.L21).

### 3.3. Effect of shear connector arrangement

It is important to know the effect of angle shear connectors arrangement on the behavior of composite section. Fig. **15** and Table 5 show the comparison of load deflection relationship between the two suggested of adopted cases study.

**Table 5** Effect of angle shear connectors arrangement

| Specimen | $P_u$ (kN) | Difference (%) |
|---|---|---|
| C.B40.L21 | 117.3 | 9.32 |
| C.B40.L22 | 107.3 | |

From experimental results, the first suggested of arrangement angle shear connector (C.B40.L21) increased by a ratio (9.32) % than the second suggested (C.B40.L22). This is due to increase of bond interaction between concrete and steel beam in the direction of shear flow.

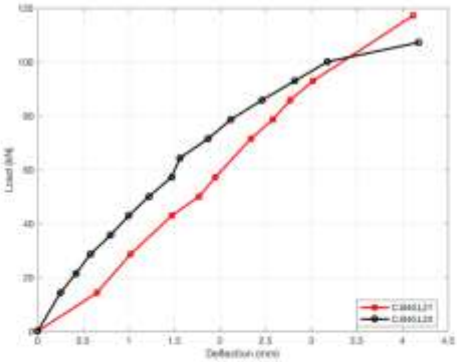


**Fig. 15** Effect of angle shear connectors arrangement

### 3.4. Effect of bond interaction

While both single and double headed and angle shear connectors were used in this investigation, the effect of bond interaction also studied. The aim of this parameter is to study the behavior of composite steel beam under negative moment with various bond interaction.

Table **6**, Table **7** and Fig. **16** show the effect of bond interaction on composite section.

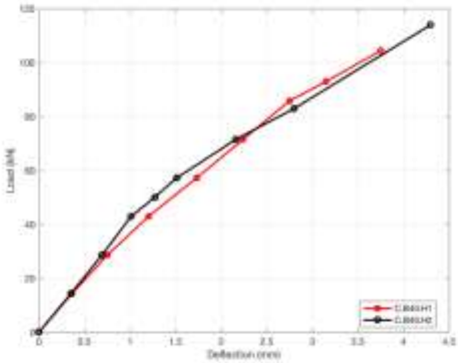
**Table 6** Effect of bond interaction for headed shear connectors

| Specimen | $P_u$ (kN) | Difference (%) |
|---|---|---|
| C.B40.H1 | 104.4 | - |
| C.B40.H2 | 114 | 9.2 |

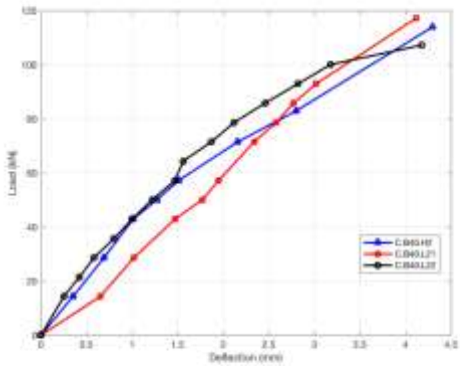
**Table 7** Effect of bond interaction for angle shear connectors

| Specimen | $P_u$ (kN) | Difference (%) |
|---|---|---|
| C.B40.L1 | 100.1 | - |
| C.B40.L21 | 117.3 | 17.2 |
| C.B40.L22 | 107.3 | 7.2 |

It observed that the ultimate strength of composite specimen with double headed studs increased by a ratio of (9.2) % than the specimen with the single headed stud which can be related to bond interaction increase. Also the same behavior for double angle shear connector for both cases was observed, i.e. the ultimate strength of composite specimen with double angle increased by a ratio of (17.2) % and (7.2) % than the composite specimen with single angle for the first and second suggested (C.B40.L21) and (C.B40.L22) respectively.



a- For headed shear connectors



b- For angle shear connectors
**Fig. 16:** Effect of bond interaction

## 4. Conclusion

From the experimental results of the adopted specimens that performed to study the behavior of angle shear connectors in the composite section subject to NBM, the main conclusions of this study are:

1. The ultimate strength decreased by a ratio of (4.12) % when the single angle shear connectors were used instead of headed stud.
2. The ultimate strength increased by a ratio of (2.89) % than the double headed stud when the first suggested arrangement of double angle shear connectors was used (C.B40.L21), while the ultimate strength decreased by a

ratio of (5.88)% than double headed stud for the second arrangement suggested (C.B40.L22).

3. The arrangement of angle shear connectors affects the behavior of composite section.
4. The first suggested of arrangement angle shear connectors (C.B40.L21) was increased by a ratio of (9.32)% than the second suggested (C.B40.L22).
5. The ultimate strength of composite specimen with double headed studs was increased by a ratio of (9.2) % than with single headed stud which can be related to the increase in the bond interaction.
6. The ultimate strength of composite specimen with double angle was increased by a ratio of (17.2) % and (7.2) % than the composite specimen with single angle for the first and second suggested (C.B40.L21) and (C.B40.L22) respectively.

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