Effect of top-hat shear connectors on the strength of cold-formed steel-concrete composite beams

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ABSTRACT

The purpose of this paper is to provide a detailed brief analysis of recent developments in various aspects of the structure of cold-formed steel. The connectors were executed from sections of a non-weld able top-hat profile (70x80x3)mm made of steel plate. The connectors were fastened to the beam with two bolts with diameter of 10mm. Totally twelve simply supported composite beam specimens are tested under two loading points to determine the flexural strength. The twelve composite beams with different thickness(2,3, and 4)mm and connection between channel(L/3, L/6) are tested. With a constant depth and a variable length of 2 and 1.5 m, the cross-section shape of the beams was maintained. The cold formed steel channel section with top hat connector at compression side is used. To avoid slip and to transfer horizontal shear between cold formed steel and concrete, the shear connectors are provided. The top hat connectors were used as shear connector between concrete and steel section. The load-deflection behavior, ultimate flexural load and failure pattern of beam had been studied. The experimental results indicate that, the load carrying capacity of the composite beams with thickness of 4mm and connection between channel with L/6 is more than the other specimen with different thicknesses and connections. The mid-span deflection at ultimate load for the composite beams was reduced in case of beam has connection L/6 and thickness 4mm. It was observed that, the steel-concrete composite beams failed due to flexural.

Keywords: composite structure, steel-concrete composite beam, cold formed steel beams, top hat shear connector, Flexural behavior

1. Introduction:

In civil engineering, cold-formed steel-concrete composite beams have been commonly used because of many advantages that develop from the combination of the mechanical properties of the main material components steel and concrete. Structural steel is characterized by high tensile strength, which helps to resist high loads, although concrete is characterized by high hardness, high compressive strength [1,2]. The cold formed steel beam is the most common variant of the composite beam. The steel section Linked by shear connectors with a concrete slab, as shown in Figure.1 [3,4].
Composite steel-concrete beams are commonly used because of their high load bearing capacity, high stiffness and ductility, as well as high capacity for energy absorption. Composite beams may be more stable, under the same architecture limitations it is cheaper than standard steel beams and thinner than traditional reinforced concrete beams[5-8]. However, the corrosivity of steel is one of the most severe flaws in composite materials. There are actually a range of ways to avoid steel corrosion, as presented in [9]. The steel-concrete composite girders can be used in floors, according to [9] Multi-span continuous bridges.

Due to the popularity of composite beams in buildings for civil engineering, composite beams are more used in civil engineering also a matter of continued growth. Proposes a new concept for steel reinforced concrete slab [10]. The board consisted of a welded steel beam with a T-shaped cross section, the gap between the grids was filled with concrete reinforcement, and reversed with steel. With a steel profile, the concrete was attached with bolts. The subject of the experimental studies of a new kind of hybrid steel-concrete beam composed of U-shaped beams steel girders were packed with concrete and attached by angled connections to the slab [11].

2. Scope

By using stiffener from steel plate with a thickness of 3mm, local buckling of cold-formed steel is avoided, so the load carrying capacity can be increased[9]. the action between concrete and steel increases the stability and serviceability status of the beam components. The hybrid beam's cross sectional diameter can be minimized relative to traditional beams. To determine the flexural behavior of cold formed steel composite with shear connectors.

- To evaluate the performance of composite beams experimentally.
- To compare the behavior of cold formed steel composite beams with different thicknesses.
- To study the load deflection behavior of composite beams.

3. Goal of work

The purpose of the work is to analyze the cold-formed steel-concrete composite beams. The top-hat profile connector, which is seen in Figure. 2. in the first part of the work is used as shear connectors. The values of normal stresses and displacements were calculated on the basis of normal stresses and displacements analysis of members. These observations were linked to the displacements acquired in the studies in experimentation.
3.1. Experimental test of composite beams

In order to investigate the effectiveness of proposed method for improving the ultimate strength, twelve composite beams were used with top hat shear connectors. The cold formed channel beam is shown in Figure 3. The Longitudinal views of the beams with top hat connectors are shown in Figure 4. The 12 specimens consisting of (1.5 and 2) m length and connection with L/3 and L/6 between two channel, each specimens of composite beams were tested. Cross sectional dimensions of Channel sections considered was 150×50×2 mm, 150×50×3 mm, 150×50×4 mm.

The steel beams was made of steel plate of different thickness (2, 3 and 4) mm as shown in (Figure 3), a galvanized trapezoidal plate of constant thickness (0.3) mm was placed as a base between the steel beams and concrete, and C30 MPa concrete was used as a concrete slab. The reinforcing mesh consist of bars with a diameter of (Ø6) mm all details reinforcing show in fig(1) and fy = 560 MPa with top hat connectors. The thickness of the concrete slab was 100 mm. The span of the beam was of (1.5 and 2) m and its width was of 0.37 m. after 28 days of curing, a concrete slab was ready to use. There were two loading points on the ceiling beam.

Figure 2. Connector made of top-hat profile

Figure 3. Geometry of cold formed channel section
3.2. Specimen’s Dimension

A channel-shape steel sections with dimensions (d=150 mm, bf =50 mm, t=(2,3and4) mm was used as root section. This section is called as cold formed steel section. The tested beams are divided into twelves beams according to span length , type of connection and thickness of the channel. All beams were tested under two symmetric point loads applied at third-span points. Also, bearing plate with dimension (100×370×15) mm is used under each load which is designed to carry the maximum load without any local crushing in concrete. Under the concentrated load and reaction points added, all specimens are stiffened with piece of stiffener have thickness 3mm. The dimensions of specimens are shown in Table (1) and Table (2).

| Designation of samples | h (mm) | length of specimen (mm) | Thickness of channel(mm) | Type of connection between channel |
|------------------------|--------|-------------------------|--------------------------|-----------------------------------|
| P1                     | 150    | 2000                    | 2                        | L/3                               |
| P2                     | 150    | 2000                    | 2                        | L/6                               |
| P3                     | 150    | 2000                    | 3                        | L/3                               |
| P4                     | 150    | 2000                    | 3                        | L/6                               |
| P5                     | 150    | 2000                    | 4                        | L/3                               |
| P6                     | 150    | 2000                    | 4                        | L/6                               |
| P7                     | 150    | 1500                    | 2                        | L/3                               |
| P8                     | 150    | 1500                    | 2                        | L/6                               |
| P9                     | 150    | 1500                    | 3                        | L/3                               |
| P10                    | 150    | 1500                    | 3                        | L/6                               |
| P11                    | 150    | 1500                    | 4                        | L/3                               |
| P12                    | 150    | 1500                    | 4                        | L/6                               |

Table (2) Reading the Specimens Designation

| Specimen designation | Reading the designations of the specimens |
|----------------------|------------------------------------------|
| P1                   | composite cold formed steel beam with double channels have thickness 2mm and type of connection L/3 and span length 2000 mm |
| P2                   | composite cold formed steel beam with double channels have thickness 2mm and type of connection L/6 and span length 2000 mm |
| P3                   | composite cold formed steel beam with double channels have thickness 3mm and type of connection L/3 and span length 2000 mm |
| P4                   | composite cold formed steel beam with double channels have thickness 3mm and type of connection L/6 and span length 2000 mm |
P5 | composite cold formed steel beam with double channels have thickness 4mm and type of connection L/3 and span length 2000 mm
--- | ---
P6 | composite cold formed steel beam with double channels have thickness 4mm and type of connection L/6 and span length 2000 mm
P7 | composite cold formed steel beam with channel have thickness 2mm and type of connection L/3 and span length 1500 mm
P8 | composite cold formed steel beam with double channels have thickness 2mm and type of connection L/6 and span length 1500 mm
P9 | composite cold formed steel beam with double channels have thickness 3mm and type of connection L/3 and span length 1500 mm
P10 | composite cold formed steel beam with double channels have thickness 3mm and type of connection L/6 and span length 1500 mm
P11 | composite cold formed steel beam with double channels have thickness 4mm and type of connection L/3 and span length 1500 mm
P12 | composite cold formed steel beam with double channels have thickness 4mm and type of connection L/6 and span length 1500 mm

### Table 3 Material characterization

| Test            | Results |
|-----------------|---------|
| Cement          | 3.15    |
| Fine aggregate  | 2.54    |
| Coarse aggregate| 2.7     |

### Materials used and Mix Proportion

#### 3.3.1. Concrete

Normal weight concrete was used to cast all slabs and one girder. The slabs was cast after 28 days from beams casting. Mixing of concrete was performed according to ASTM C192/C192M [12]. The mold was removed after 24 hours of the casting, and then burlap sacks were placed and kept wet through 28 days,

- **Cement**
  
  Sulphate resisting cement (type KAR) was the type of cement used in this research, respect that satisfied (IQS No. 5/1984) limitations [13].

- **Fine Aggregate**
  
  Natural local sand conforms according to the limits of Iraq specification (IQS No.45/1984) and Consultative Reference Guide (No.500/1994) Weighted Method. Zone (2).[14]

- **Coarse Aggregate**
  
  Natural crashed gravel with a maximum size of (19) mm is used as the coarse aggregate. Mechanical and chemical properties were accepted according to the requirements of (IQS No.45/1984) and Consultative Reference Guide (No.500/1994) Weighted Method.[14]

- **Admixture.**
  
  Flocrete (SP90S) High range water reducing admixture with workability retention properties complies with ASTM C494, Type B, D and G, depending on the dose.
Based on the properties of the materials obtained and the specifications the mix proportion for concrete, the obtained mix proportion is shown in Table 4

| Table (4) Mix Proportion |
|-------------------------|
| **Cement (Kg/m³)**      | **Fine Aggregate (Kg/m³)** | **Coarse Aggregate (Kg/m³)** | **Water (Kg/m³)** | **Super plasticizer SP90S (kg/m³)** |
| 350                     | 790                        | 1115                         | 130               | 4.5                                   |

- **Reinforcing Steel**

Deformed steel bars with two different diameters. The tests were carried out on the (6 mm) nominal diameter bars to find the yielding and ultimate strength. The recorded data are presented in Table (5) according to ASTM A615 [17].

| Table (5) Tensile Test results of Steel Reinforcing Bars |
|--------------------------------------------------------|
| Diameter (mm)                                         | Yield stress* (MPa) | Ultimate strength* (MPa) |
| Nominal                                               | Measured*           |                          |
| 6                                                     | 5.75                | 560                      | 602               |

*Steel bars were tested by using universal testing machine in Al-Musayyib Technical Institute.

**Assume modules of elasticity (E) = 200×10³ MPa

3.3.2. Cold Formed Steel

Cold-formed steel is a category of steel that is made, refined and extracted at room temperature by grinding the steel. In all aspects of the building industry, mechanical industry, electrical industry etc., cold rolling sheets are commonly used. The manufacture process of cold-formed steel products will be carried out at room temperatures, and pressing and rolling are used in the manufacturing process[15]. Cold-formed sheets of 2,3 and 4 mm thick steel were used. The cold-formed steel sheets provided by the method of press break in the form of the channel portion. For both specimens, the depth of 150mm is kept constant.

3.3.3. Shear Connectors

Shear connections are designed to shift the longitudinal shear along the interface and also to help resist the separation of concrete at the interface from the steel beams[16]. The top hat form shear connectors were used. Figure 5 shows the cross sectional axis of the shear connector. Two bolts (10)mm diameter attach the shear connections to the cold-formed steel beam.

![Figure 5](image_url)
3.4. Casting of Beams

After producing channel sections with shear connections, the specimens were painted only to the outside of the channel sections with primer paint and held for drying. By mixer power, Concrete was mixed and was poured onto the beam and sheets were held as type work at the ends as seen in Figure 6. Channel parts were filled with gunny bags after 24 hours of casting, and curing was done for 28 days. The 3-number of concrete cubes were cast and tested to assess the compressive strength for 28 days. The average compressive strength of the cubes for 28 days is 37 N/mm2.

![Figure 6. Casting of Concrete](image1)

![Figure 7. Compressive Testing of Cubes](image2)

4. Testing Procedure

In the Structures Laboratory of the Department of Structural Engineering at the University of Babylon, twelve simply supported composite beams were tested under two equivalent concentrated loads before failure occurred using a 600 kN capacity hydraulic testing unit. All the beams were mounted on a roller at one end and on a hinge at the other. as supports and at loading points, bearing plates were used to resist local yield in steel and local crushing in concrete, respectively. The load is then applied, the initial reading of the deflection, is registered. The specifics of the machine and lateral frames used for measuring beams are seen in Figure (8).
Figure 8. The machine and lateral frames used for measuring beams

![Machine and Lateral Frames](image)

a) span 2000 mm  

b) span 1500 mm

Figure 9. Geometry of cold formed steel-concrete composite beam with the connector made of top-hat profile under two point load, mm

Using the hydraulic jack, load was progressively added in increments until the specimens failed. Throughout the loading range, the behavior of the beams was observed. The beam deflection was recorded by dial gauge. For each beam, load deflection curves were manually collected. The occurrence of isolation, crack propagation and slip have also been observed and reported.

![Beam Test](image)

a) Crack width  

b) Beam after failure

Figure 10. Type of Failure for beam p1
5. Result and discussion

5.1 load versus mid-span deflection results

The dial-gauge was installed on the middle span during the test of all the girders to record the deflection of the girders to study the behavior of the load-Deflection curves and then determine the ratio of stiffness and ductility. For all tested girders, experimental load deflection curves are seen in Figure 13 to Figure 18

5.1.1. First group

The test consists of six samples with a length of 2 meters and different thicknesses and contact between samples L/6 and L/3.

The first and second samples consist of a thickness of 2 mm, the third and fourth with a thickness of 3 mm, and the fourth and fifth with a thickness of 4 mm. Half of the previous samples were the process of contacting them on the L/3 method and the second half on the L/6 method by examining those samples gave the models with a thickness of 4 mm higher. The results, with the same group, gave the contact method L/6 higher than the first method, with a difference of 12% more from (L/3) connection method, and as shown in the following table 6 and figures (13-15)
Table 6. The values of ultimate load, Ultimate Deflection

| samples | thickness of channel (mm) | Length span, L (mm) | type of connection | ultimate load (KN) | ultimate deflection (mm) | % increase in ultimate load | % decrease in deflection |
|---------|--------------------------|---------------------|-------------------|-------------------|--------------------------|---------------------------|--------------------------|
| P1      | 2                        | 2000                | L/3               | 128               | 28                       | ---                       | ---                      |
| P2      | 2                        | 2000                | L/6               | 139               | 26.3                     | 8.59                      | 6.07                     |
| P3      | 3                        | 2000                | L/3               | 148               | 23                       | ---                       | ---                      |
| P4      | 3                        | 2000                | L/6               | 167               | 21.4                     | 12.83                     | 6.95                     |
| P5      | 4                        | 2000                | L/3               | 178               | 26                       | ---                       | ---                      |
| P6      | 4                        | 2000                | L/6               | 185               | 21.9                     | 3.93                      | 15.76                    |

Figure 13. Load-Deflection Curves for P1 and P2 and P3 and P4

Figure 14. Load-Deflection Curves for P5 and P6

5.1.2. Second group

The set consists of six samples with a length of 1.5 meters and different thicknesses and contact between samples.

The first and second samples are 2 mm thick, the third and fourth samples are 3 mm, and the fourth and fifth samples are 4 mm thick. Half of the previous samples were contacted by the L/3 method, and the second half by the L/6 method. By testing these samples, samples with thickness of 4 mm gave higher
results, with the same group, the contact method gave $L/6$ give higher strength than the first method, with a difference of 18%. Also, the values of the deflection in the samples containing the connection $L/3$ were less than those of the samples that obtained the connection $L/3$ in addition to this group gave a higher strength than the previous group due to the decrease of length and as shown in the drawings. The following table and figures show ultimate load and deflection

| samples | Thickness of channel (mm) | Length Span, L (mm) | Type of connection | Ultimate Load (KN) | Ultimate Deflection (mm) | % increase in Ultimate load | % decrease in Deflection |
|---------|--------------------------|---------------------|--------------------|---------------------|--------------------------|-----------------------------|--------------------------|
| P7      | 2                        | 1500                | L/3                | 140                 | 16.3                     | ----                        | ----                     |
| P8      | 2                        | 1500                | L/6                | 153                 | 13                       | 35.64                       | -20.24                   |
| P9      | 3                        | 1500                | L/3                | 193                 | 22.5                     | ----                        | ----                     |
| P10     | 3                        | 1500                | L/6                | 209                 | 21.3                     | 8.29                        | -5.33                    |
| P11     | 4                        | 1500                | L/3                | 237                 | 18.65                    | ----                        | ----                     |
| P12     | 4                        | 1500                | L/6                | 248                 | 17.4                     | 4.64                        | -6.7                     |

Figure 15. Load-Deflection Curves for P7 and P8 and P9 and P10

Figure 16. Load-Deflection Curves for P11 and P12

5.2 Ultimate Load

The ultimate load is concerned with the power or load carrying capability component of the structural actions of the beams. The ultimate load of beams with top hat shear connector checked experimentally are seen in figure 20. The beam with top hat shear connector and thickness of channel 4 mm and link
between channel L/6 carries more load than the beam with same cross section with L/3 connectors in two groups by (44.53%) for groups one and (77.14%) for groups two.

**Figure 17.** Ultimate Load

### 6. Conclusion

A new composite beam and floor structure using continuous cold formed top hat as a shear connector has been proposed. The study of the bending power and actions of the proposed composite beam of cold-formed steel joists and concrete slab has been carried out experimentally in this paper. Furthermore, the load–deflection behavior of proposed composite segment has been included in the experimental investigation and the test findings are matched between two group Centered on the experimental findings received, the following assumptions can be drawn:

1. The study of twelve cold formed composite beams indicates that the proposed system presents the better performance of structural ability for both ultimate strength of the section. Based on present test results, the ultimate strength of proposed composite section can be increased by thickness of channel and connection between them.

2. The cold-formed top hat shear connector can help distribute the transfer mechanism of horizontal shear force. According to the load measurements, the proposed composite section shows a better continuity of behavior than the previous study.

3. Through the results, it was found that samples with a thickness of 4 mm and connection between two channel (L/6) had the highest strength compared to the other case of the same sample, where the difference between the other of the models was from (3.93%-12.83%) for first group and increase in strength in second group was (4.64%-35.64%).

4. The amount of deflection in the second group was smaller than in the first group, and the reason for this was due to the increase in the force arm. Also, the amount of deflection in samples with a thickness of 4 mm was less than with the other models where the amount of deflection was for the first group (6.07%-15.76%) and the amount of deflection was for the second group (6.7%-20.24%).

### References:

[1] C.G. Chiorean, S.M. Buru, Practical nonlinear inelastic analysis method of composite steel-concrete beams with partial composite action, Engineering Structures 134 (2017) 74–106. https://doi.org/10.1016/j.engstruct.2016.12.017.
[2] P. Lacki, J. Nawrot, A. Derlatka, Numerical analysis of segment of steel-concrete bridge girder loaded by dead load, Zeszyty Naukowe Politechniki Częstochowskiej, Budownictwo 172 (2017) 204–212. https://doi.org/10.17512/znb.2016.1.20.

[3] P. Lacki, P. Kasza, A. Derlatka, Numerical Analysis Of Prefabricated Steel-Concrete Composite Floor In Typical Lipsk Building, Civil and Environmental Engineering Reports 27 (2017) 43–53

[4] Tahir, M. M., Lawan, M. M., Saggaff, A., & Mirza, J. (2016). Influence of Shear Connector Size on Ultimate Strength in Composite Construction with Cold-Formed Steel Channel Lipped Section. Review of Industrial Engineering Letters, 3(1), 1–10. https://doi.org/10.18488/journal.71/2016.3.1/71.1.1.10

[5] D. Fa-xing, L. Jing, L. Xue-mei, Y. Zhi-wu, L. Yong-suo, Experimental investigation on hysteretic behavior of simply supported steel-concrete composite beam, Journal of Constructional Steel Research 144 (2018) 153–165. https://doi.org/10.1016/j.jcsr.2018.01.018.

[6] P. Lacki, J. Nawrot, Numerical Analysis Of Bridge Girder With Composite Dowel Shear Connection, Civil and Environmental Engineering Reports 27 (2017) 55–65.

[7] K. Furtak, Evaluation of the influence of shrinkage strain on the fatigue strength of the connection in steel–concrete composite beams, Archives of Civil and Mechanical Engineering 15 (2015) 767–774. https://doi.org/10.1016/j.acme.2014.12.011.

[8] C. Machelski, R. Toczkiewicz, Effects of connection flexibility in steel-concrete composite beams due to live loads, Archives of Civil and Mechanical Engineering 6(2006) 65–86. https://doi.org/10.1016/S1644-9665(12)60077-6.

[9] T. Wang, H. Ge, K. Zhang, A novel core-shell silica@graphene straticulate structured antistatic anticorrosion composite coating, Journal of Alloys and Compounds 745 (2018) 705–715. https://doi.org/10.1016/j.jallcom.2018.02.222.

[10] J. Derysz, P.M. Lewiński, P.P. Więch, New Concept of Composite Steel-reinforced Concrete Floor Slab in the Light of Computational Model and Experimental Research, Procedia Engineering 193 (2017) 168–175. https://doi.org/10.1016/j.proeng.2017.06.200.

[11] Y. Liu, L. Guo, B. Qu, S. Zhang, Experimental investigation on the flexural behavior of steel-concrete composite beams with U-shaped steel girders and angle connectors, Engineering Structures 131 (2017) 492–502. https://doi.org/10.1016/j.engstruct.2016.10.037.

[12] ASTM C192/C192M “Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory”, 2002.

[13] Iraqi Specification Standards “Portland Cement IQS No. (5),” Central Agency for Standardization and Quality Control, Baghdad, IRAQ, 1984 (in Arabic).

[14] Iraqi Specification, No.45, “Aggregate from Natural Sources for Concrete and Construction”. Baghdad, Iraq, 1984.

[15] Hancock, G. J., Murray, T., & Ellifrit, D. S. (2001). Cold-Formed Steel Structures to the AISI Specification. In Cold-Formed Steel Structures to the AISI Specification. https://doi.org/10.1201/9780203907986

[16] Helbrych, P., Major, M., & Nawrot, J. (2017). Numerical and Experimental Analysis of a Shear Connection Made Using a Top-Hat Profile. Civil and Environmental Engineering Reports, 26(3), 69–78. https://doi.org/10.1515/ceer-2017-0036

[17] ASTM A615 / A615M-16, Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement, ASTM International, West Conshohocken, PA, 2016, www.astm.org