Load-slip relationship of multi-type shear connectors based on push-out test

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Abstract: The push-out test used in this study to present the performance of continuous perfobond connectors. A total of seven specimens that are composed of lightweight concrete-filled steel tubes with two reinforced blocks were tested. The main investigated parameters were the concrete compressive strength of the blocks, specification of perfobond shear connector, and the type of shear connector. Specimens were inspected under a concentrated load applied on the steel tube filled with lightweight concrete while the slip is measured by two LVDTs. The results show that the ultimate shear strength and stiffness are increasing with increment concrete compressive strength. The T-type and mixed-type show increase in the ultimate shear strength compared with perfobond type, while a maximum slip of specimens decreasing with increasing the compressive strength of the concrete.

Keywords: Concrete-filled steel tube (CFST), Lightweight concrete, T-type rib connector, Push-out test, Perfobond connector, Reinforced concrete, Compressive strength.

1. Introduction

The shear connectors are used to resist the horizontal and vertical displacement between the steel and concrete, the horizontal displacement called slip, while the vertical displacement called uplift [1,2]. The most important factor for designing the composite structure is a load-slip relationship because it's going to set the linear and nonlinear behavior of the shear connection, the push-out tests are a very appropriate way to determine this relationship. The first studies were about stud connectors, with different diameters, lengths, and spaces between the connectors there are some proposed expressions to predict the load-slip relation for stud connector [3–5]. There are many types of connectors such as headed stud, channel, T-type, waveform-strip, perfobond, Oscillating-perfobond shear connectors as shown in Figure 1 [6–8]. There are many applications of perfobond connectors used to connect the CFST (concrete-filled steel tube) members with concrete beam, foundation, or slab as shown in Figure 2 [9–12]. The concrete-filled steel tube (CFST) member consists of a steel tube filled with concrete, CFST has many advantages such as high strength, more ductility, and low cost [13–15]. It can observe three-stage in the curve of the slip load of perfobond connector for the push out test as shown in Figure 3 [9]. The first called the initial stage, this stage is elastic. The second stage is the Elasto-plastic stage, the last stage is the post-failure stage [9]. There are many studies that have been done to test the performance of perfobond connector and some expressions were suggested to expect the load slip relation for different types of perfobond connectors.

Zheng et al. [9] studied the behaviour of perfobond shear connectors, the experimental study includes tested seventy-two specimens. The authors concluded that the push-out test of the perfobond connector depending on many variables such as hole geometry, concrete compressive strength, concrete slab dimensions, the arrangement of bars on the holes of the connector, and perfobond dimensions. The
authors suggested an equation to estimate the load-slip curve of perfobond connector including wide range parameters.

(a) Strengthening of the pile cap,  
(b) composite trusses.

**Figure 2.** Perfobond connectors[9].

Oguejiofort and Hosain [16]. studied the behaviour of the perfobond shear connector. The main goal of the study was finding the ultimate capacity of this type of shear connector by using the finite element technique. The equation estimated from the study shows a good agreement when compared with experimental studies. Ahn et al. [17] studied the single and twin perfobond connectors. The key objective of the study is to find the best way of arranging the perfobond connector and use it in the design and construction of the composite girder. The details of the test specimens were shown in Figure 4. The experimental results were compared with some of the equations that were suggested by other studies, the results of the single perfobond connector were less than estimated values while the results of the double perfobond connector were above the estimated values, so the equation was modified to match the experimental results of this type of perfobond connector. Zheng. et al [18] studied the perfobond shear connector, the study has two lines (experimental and numerical). In the experimental program, the authors tested twenty-one specimens. The goal of the study is to find the ultimate shear capacity, failure mode, and the behavior of slip during the test. The numerical analysis includes the study of eighty-seven specimens. The theoretical study focused on the effect of concrete compressive...
strength and hole shape. The authors suggested an equation to represent the behavior of perfobond shear connector, this equation based on hole size, concrete compressive strength, area of the transverse bar, and yield stress of the transverse bar.

![Figure 3](image_url)

**Figure 3.** Load slip stages identifications [9].

![Specimens](image_url)

Specimen of the single perfobond. Specimen of the twin perfobond.

**Figure 4.** Details for push-out tested specimens Ahn et al. [17].

Chung et al. [19] studied a T-type Perfobond shear connector for composite beams, and a group of push-out tests is done with several parameters, like length and thickness of the rib shear connector, diameter and number of the holes in the ribs, number of transversal reinforcing steel bars, and strength of concrete. From test results, the effect of each parameter is analyzed. In addition, a shear strength formula was suggested for a 0.4 m long T-type Perfobond rib shear connector as shown in Figure 5. The comparison of the test and the calculation results showed a good agreement.
SU and Wang [20] tested a new type of perfobond shear connector known as corrugated perfobond shear connector. The authors concluded that the behavior of the corrugated connector is very good; also, they found the load-slip curve for this type of shear connector. The shear capacity of the corrugated connector was higher than the shear capacity of the ordinary perfobond connector by 24%.

Li et al. [21] investigated the push-out test experimentally and numerically of corrugated perfobond connectors. The findings show that many factors such as concrete compressive strength, the yield stress of transverse bar, the size of the hole, area of the corrugated connector, and area of the horizontal projection of the corrugated perfobond shear connector affect the performance of the shear-slip. A new mixed type of combined connectors was suggested by Zheng et al. [22]. The authors studied a new combined type (stud with perfobond connector) experimentally and numerically. The authors tested nine specimens in the experimental program, the goal of the experimental test was to compare the behavior of stud connector, perfobond connector, and the new mixed connector. The theoretical study included additional variables such as connector dimensions and properties of materials. The results show that the shear strength of the mixed connector depending on many factors such as transverse bar dimension, stud size, stud properties, hole size, concrete compressive strength, and properties of a transverse bar.

Ibrahim et al.[23] carried out an experimental shear program of the push-out test. The authors test twelve push-out specimens classified into four groups. This study consists of three types of shear connectors (angle, stud, and perfobond connectors). The purpose of the study is to identify the behavior of the shear connector also find the stiffness and the shear strength of these types of shear connectors. Failure modes, shear strength, load-slip curve, and connector stiffness were the key outcomes. The shear capacity of the perfobond connector higher than the shear capacity of the stud and angle connector. Zheng et al. [24] studied the performance of an alternative notched perfobond connector experimentally and numerically, one of the most advantages is to easy construction of perforating reinforcement bars. The experimental program includes tested of six specimens, while the numerical program included analysis of forty-three specimens. Finally, the authors suggested an analytical model calculate the shear strength capacity of this type of perfobond connector.

The relationship between the slip and horizontal shear resistance in perfobond connectors is depending on the number of reinforcement bars used in perfobond connectors and the properties of these bars. The concrete used for filling the steel tube is lightweight concrete. In this study, a continuous perfobond connector with a concrete-filled steel tube (CFST) used to study the effect of compressive strength, type of shear connector (perfobond, T-type, and mix of them), bar diameter that used in perfobond connector, and effect of filling the steel tube.

2. Experimental program
Seven specimens were prepared for testing; each specimen consists of a concrete-filled steel tube of 500 mm length and two reinforced concrete blocks of 500x450x100 mm as shown in Figure 6. The lightweight concrete was used to fill the steel tube; the details of the specimens are listed in Table 1. The nomenclature of the specimen has three sections, the first section (S25 and S0) refer to concrete strength that filled square steel tube, and S0 means hollow steel tube. The second section refers to the
shear connector type (Ø8, T, TØ8) Ø8 mean perfobond shear connector with bat diameter 8 mm, T refers to shear connector type T, and TØ8 mean mix type of shear connector (perfobond and T type). Finally, the third section refers to the strength of concrete blocks (40 and 60 MPa). Perfobond connector with dimensions 450x70x10 mm. Two LVDTs were used one on each block to record the slip between the steel tube and the concrete block. The arrangement of this test according to Eurocode 4 [25].

Table 1. Details of specimens

| Specimen     | Concrete strength (MPa) | connector | type          | Size (mm) |
|--------------|-------------------------|-----------|---------------|-----------|
| S25-Ø8-40   | 40                      | perfobond | Ø8            |           |
| S0-Ø8-40    | 40                      | perfobond | Ø8            |           |
| S25-Ø12-40  | 40                      | perfobond | Ø12           |           |
| S25-Ø8-60   | 60                      | perfobond | Ø8            |           |
| S25-T-40    | 40                      | Plate     | 70*80         |           |
| S25-T-60    | 60                      | Plate     | 70*80         |           |
| S25-TØ8-40  | 40                      | Plate + perfobond | Ø8 + 70*80 |

Figure 6. Specimen details.
3. Material Properties
Two types of normal concrete were used for the blocks and lightweight concrete was to fill the steel tube. The lightweight concrete used clay aggregate (LECA) as gravel. Details of concrete mixtures properties are summarized in Table 2. The normal concrete was designed consistent with American Concrete Institute 211.1-91, while the lightweight concrete was designed consistent with ACI Committee 211.2-98. The values of yield stress and ultimate strength of the steel reinforcement, steel tubes, and perfobond connector are listed in Table 3.

| Mix                  | Mixing ratio | W/C ratio | S.P ratio of cement | Compressive strength (MPa)* | Casting part |
|----------------------|--------------|-----------|---------------------|----------------------------|--------------|
| M1 (LWC) = 25        | 1 : 1.75 : 0.5 | 0.3      | 0.4%                | 23.08                      | inside tube  |
| M2 (Normal) = 40     | 1 : 1.875 : 2.75 | 0.3      | 0.1%                | 38.91                      | Concrete block |
| M3 (Normal) = 60     | 1 : 1.24 : 2.05 | 0.24     | 0.28%               | 61.1                       | Concrete block |

# Cube compressive strength at 28 days.

4. Testing procedure
The load was applied with increases of 5 kN; the procedure of investigation was done in agreement with Eurocode 4 [25]. Two of LVDTs are used to record a displacement between concrete blocks and CFST; the locations of LVDTs are shown in Figure 7.

![Figure 7. Push-out test.](image-url)
5. Results and Discussions.
The results obtained from the experimental tests show that the specimens have cracks in the concrete blocks at the final stage of loading. Table 4 shows the ultimate shear force and corresponding slip at this load. Figure 8 shows the push-out specimens test after the end of loading.

Table 4. Test results of push-out specimens.

| Specimen | Ultimate shear Vu (kN) | Improve in Vu % | Slip @ Vu (mm) | Stiffness Ki (kN/mm) |
|----------|------------------------|-----------------|----------------|---------------------|
| 1        | 406.26                 | -               | 5.72           | 95.3                |
| 2        | 324.07                 | -20.23%         | 4.55           | 94.2                |
| 3        | 636.36                 | 56.63%          | 6.35           | 112.9               |
| 4        | 513.58                 | 26.42%          | 5.19           | 101.5               |
| 5        | 759.26                 | 86.89%          | 6.1            | 155.9               |
| 6        | 734.16                 | 80.71%          | 6.86           | 145.2               |
| 7        | 792.59                 | 95.09%          | 5.11           | 357.2               |

All tests of push-out continued until failure appeared, two forms of failure have appeared in the concrete blocks. The first was the formation of cracks in the longitudinal direction parallel to the steel plate (shear connector), while the second was the crushing of the concrete blocks that appeared at the bottom of blocks. A single specimen has local buckling (S0-Ø8-40) as shown in Figure 8; the reasons for the emergence of this type of failure can be refer to the lack of concrete inside the steel tube.

After the end of the tests, the concrete blocks removed and broken to find out what happened to the reinforcement steel bar that penetrates the shear connector in the perfobond connector and T connector. It was found that the bars underwent a large deformation. Figure 9 illustrates these deformations, from this figure it can be seen that the bars used in the perfobond connector have a V shape in the mid of the bar the reason for these deformations is due to the large shear force during the test. Specimen S25-T-60 subjected to high shear forces that led to the welding failure and separation of the flange from one side as shown in Figure 9.

Figure (10) shows the load-slip for push-out specimens test, from Figure (10) and Table 4 the ultimate shear force of reference specimen (S25-Ø8-40) is 406.26 kN, and the corresponding slip at this load 5.72 mm while the initial stiffness is 95.3 kN/mm. The effect of the hollow steel tube is the first parameter of the push-out specimens, the specimen S0-Ø8-40 represent this parameter. The ultimate shear force of the S0-Ø8-40 specimen is 324.07 kN, and the corresponding slip at this load 4.55 mm. Figure (11 A) shows the effect of filling the steel tube on the load-slip relation. The ultimate shear force decreases by 20.23 % this decrease can be attributed to the local buckling that occurred in the steel tube, and this buckling is caused by the lack of fill-in concrete inside the steel tube.

The effect of compressive strength of the concrete blocks is considered one of the main factors in the push-out tests. Therefore, the effect of compressive strength was studied on two types of connectors (perfobond and T connector). Figures (11- B) and C show the influence of compressive strength on load-slip relation for perfobond connector and T connector. From these figures and Table 4, the maximum shear force of the S25-Ø8-60 specimen is 513.58 kN, and the corresponding slip at this load 5.19 mm, the increase in the maximum force 26.428% when compared with specimen S25-Ø8-40, also the initial stiffness increased to 101.5 kN/mm. The influence of deck slab compressive strength on load-slip relation of “T” connector shown in Figure (11- C). From this figure and Table 4, the maximum shear force of the S25-T-40 and S25-T-60 specimens are 734.0, and 759.26 kN respectively, the corresponding slip at these loads 6.86, and 6.1 mm respectively, the increase in the maximum force 3.44% for specimen S25-T-60 when compared with S25-T-40. The initial stiffness of specimens S25-T-40 and S25-T-60 are 145.2 and 155.9 kN/mm respectively. These increases in the maximum shear force of specimens S25-Ø8-60 and S25-T-60 coming from developing the compressive strength of the concrete blocks. However, the slip at the maximum load will be decreasing with increasing concrete compressive strength for all specimens.
Figure 8. Failure mode of push-out specimens.
Figure 9. Deformation of steel reinforcement and rib shear connector.
The effect of bar diameter in the perfobond shear connector investigated by specimen S25-Ø12-40, in this specimen the bar diameter used 12 mm instead of 8 mm. Figures (12-A) shows the effect of bar diameter in the perfobond shear connector on load-slip relation. From this figure and Table 4, the maximum shear force of the S25-Ø12-40 specimen is 636.36 kN, and the corresponding slip at this load 6.35 mm, the increase in the maximum force 56.63% when compared with specimen S25-Ø8-40, also the initial stiffness increased to 112.9 kN/mm. The effect of shear connector type is considered one of the major factors in the load-slip tests. Therefore, the effect of shear connector type was studied on three types of connectors (perfobond, "T", and mix of perfobond and "T" connector). The mix of perfobond and "T" connector shown in Figure (12 B). Figure (12 C) shows the effect of connector type on load-slip relation for perfobond, "T" and mix of perfobond and "T" connector for compressive strength of 40 MPa. From this figure and Table 4, the maximum shear force of the S25-T-40 and S25-TØ8-40 specimens are 734 and 792 kN respectively, and the corresponding slips at these loads 6.86 and 5.11 mm respectively. The increase in the maximum force 80.71% and 95.09% when compared with specimen S25-Ø8-40, also the initial stiffness of the S25-T-40 and S25-TØ8-40 specimens increased to 145.2 and 357.2 kN/mm respectively. Figure (12 D) shows the effect of connector type on load-slip relation for perfobond, and "T" for compressive strength of 60 MPa. From this figure and Table 4, the maximum shear force of the S25-Ø8-60 and S25-T-60 specimens are 513.58 and 759.26 kN respectively, and the corresponding slips at these loads 5.19 and 6.1 mm respectively. The increase in the maximum force of specimen S25-T-60 is 47.83% when compared with specimen S25-Ø8-60. The initial stiffness of S25-Ø8-60 and S25-T-60 specimens are 101.5 and 155.9 kN/mm respectively. In general, the T-type connector showed higher ultimate shear force and initial stiffness than the perfobond connector type.
Figure 11. Concrete compressive strength effect on the load-slip relationship.

(A) Influence of fill-in concrete in a steel tube on the load slip curve.

(B) Effect of compressive strength on load-slip curve for perfobond connector.

(C) Influence of concrete compressive strength on load slip curve for T-type connector.
Figure 12. Effect of shear connector parameter on load-slip curve.

(A) Effect for bar diameter of perfobond shear connector parameter.

(B) Mix of perfobond and T-type connector.

(C) Effect of shear connector type for concrete strength 40 MPa.
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6. Conclusion
The followings can be drawn as the most important concluding remarks from the experimental work conducted in this study,

1. The specimen of the push-out with a hollow steel tube failed by buckling for the steel tube and exhibited smaller ultimate shear strength, and slip at the failure by 20.23 % and 20.45 % respectively than the specimen of the concrete-filled steel tube.
2. The increase in the bar diameter of the perfobond shear connector from 8 mm to 12 mm leads to an increase in the ultimate shear strength (56.36 %) and initial stiffness (18.47 %).
3. The increase in the compressive strength of concrete blocks from 40 MPa to 60 MPa leads to an increase in the ultimate shear strength (26.42 %) and initial stiffness (6.51 %) while the slip at the maximum shear reduced by 9.27 %.
4. Three types of shear connectors perfobond, T-type, and mixed-type of perfobond and T-type were tested. The T-type and mixed-type were show increase in the ultimate shear strength compared with perfobond by 82.72 % and 95.1 % respectively for 40 MPa compressive strength. The same behavior was shown in the initial stiffness of these connectors at the same compressive strength (40 MPa).
5. For 60 MPa compressive strength, two types of shear connectors perfobond and T-type were tested. The T-type showed an increase in the ultimate shear strength compared with perfobond by 47.84 %, also the initial stiffness for T-type increased by 53.6 % at the same compressive strength (60 MPa).

References
[1] Shallal M A, Almusawi A M and MUSSA F I 2018 Non-linear analysis of continuous composite beams subjected to fire Int. J. Civ. Eng. Technol. 9 521–32
[2] Shallal M A and Al Musawi A M K 2018 Non-linear analysis of composite beam subjected to fire J. Eng. Appl. Sci. 13 9643–50
[3] Lorenc W and Kubica E 2006 Behavior of composite beams prestressed with external tendons: Experimental study J. Constr. Steel Res. 62 1353–66
[4] Xue W, Ding M, Wang H and Luo Z 2008 Static Behavior and Theoretical Model of Stud Shear Connectors J. Bridg. Eng. 13 623–34
[5] Prakash A, Anandavalli N, K. Madheswaran C and Lakshmanan N 2012 Modified Push-out Tests for Determining Shear Strength and Stiffness of HSS Stud Connector-Experimental Study Int. J. Compos. Mater. 2 22–31

[6] Ali Shariati 2012 Various types of shear connectors in composite structures: A review Int. J. Phys. Sci. 7

[7] Farhan K A and Shallal M A 2019 Push-out Tests for Determining Shear Strength and Stiffness of Perfobond Connector-Experimental Study Al-Qadisiyah J. Eng. Sci. 12 225–31

[8] Alnebhan K M and Shallal M A 2020 Experimental and numerical investigations on the behaviour of concrete filled steel tube and channel shear connectors in push-out tests IOP Conf. Ser. Mater. Sci. Eng. 870 0–14

[9] Zheng S, Zhao C and Liu Y 2018 Analytical model for load-slip relationship of perfobond shear connector based on push-out test Materials (Basel). 12

[10] Farhan K A and Shallal M A 2020 Experimental behaviour of concrete-filled steel tube composite beams Arch. Civ. Eng. 66 235–51

[11] Alnebhan K M, Shallal M A 2020 Composite concrete and concrete filled steel tube (CFST) truss girders Structural Integrity and life 20 103–12

[12] Alnebhan K M and Shallal M A 2020 Effect of filling steel tube chords by concrete on the structural behaviour of composite truss girders Al-Qadisiyah J. Eng. Sci. 13 167–74

[13] Shallal M A 2018 Flexural behavior of concrete-filled steel tubular beam 2018 International Conference on Advance of Sustainable Engineering and its Application (ICASEA) (IEEE) pp 153–8

[14] Thejeel M M and Shallal M A 2019 Experimental Study of Self-Compacted Concrete-Filled Steel Tube (CFST) Truss Girders Al-Qadisiyah J. Eng. Sci. 12 98–104

[15] Thejeel M M and Shallal M A 2020 Performance of concrete-filled steel tube truss girders strength by adding reinforcement IOP Conf. Ser. Mater. Sci. Eng. 870

[16] Oguejiofor E C and Hosain M U 1997 Numerical analysis of push-out specimens with perfobond rib connectors Comput. Struct. 62 617–24

[17] Ahn J H, Lee C G, Won J H and Kim S H 2010 Shear resistance of the perfobond-rib shear connector depending on concrete strength and rib arrangement J. Constr. Steel Res. 66 1295–307

[18] Zheng S, Liu Y, Yoda T and Lin W 2016 Parametric study on shear capacity of circular-hole and long-hole perfobond shear connector J. Constr. Steel Res. 117 64–80

[19] Chung C H, Lee J and Kim J S 2016 Shear strength of T-type Perfobond rib shear connectors KSCE J. Civ. Eng. 20 1824–34

[20] Su Q T and Wang D F 2011 Strength and Stiffness of Corrugated Rib Connector Advanced Materials Research 243 1497–503

[21] Li S, Su L and Sun Z 2018 Research on the Load-slip Properties of Corrugated Rib Connectors’ Push-out Test KSCE J. Civ. Eng. 22 1258–64

[22] Zheng S, Zhao C and Liu Y 2019 Parametric Push-Out Analysis on Perfobond Rib with Headed Stud Mixed Shear Connector Adv. Civ. Eng. Article ID 5952319

[23] Ibrahim A M, Mubarak H M and Said A I 2018 Experimental study of push-out test of circular steel tube with various types of shear connectors 1st Int. Sci. Conf. Eng. Sci. - 3rd Sci. Conf. Eng. Sci. ISCES 2018 - Proc. 2018-Janua 265–70

[24] Zheng S, Liu Y Y, Liu Y Y and Zhao C 2019 Experimental and numerical study on shear resistance of notched perfobond shear connector Materials (Basel). 12 1–20

[25] CEN E N 2004 1-1: “Eurocode 4: Design of composite steel and concrete structures-Part 1-1: General rules and rules for buildings” Brussels, Belgium